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CONTENTS

REVIEW SECTION

REFERENCE SECTION

IGR TRANSLITERATION OF RUSSIAN

The AGI Translation Office has adopted the Cyrillic transliteration recommended by the U. S. Department of the Interior, Board on Geographic Names, Washington, D.C.

Alphabet		transliteration
А	а	a
Б	б	b
В	в	v
Г	г	g
Д	д	d
Е	е	e, ye (1)
Ё	ё	ë, yë
Ж	ж	zh
З	з	z
И	и	i
Й	й	y
К	к	k
Л	л	l
М	м	m
Н	н	n
О	о	o
П	п	p
Р	р	r
С	с	s
Т	т	t
У	у	u
Ф	ф	f
Х	х	kh
Ц	ц	ts
Ч	ч	ch
Ш	ш	sh
Щ	щ	shch
Ъ	ъ	''
Ы	ы	y
Ь	ь	'
Э	э	e
Ю	ю	yu
Я	я	ya

NOTES:

(1) "ye" initially, after vowels, and after ъ, ь ; "e" elsewhere; when written as "ë" in Russian, transliterate as "yë" or "ë".

Well-known place and personal names that have wide acceptance will be used. Some translations may include elements of previous German transliteration from the Russian; this occurs in IGR most commonly in maps and lists of references. The reader's attention is called to the following variations between German and English systems which may cause confusion when trying to check back to original Russian sources.

German	English
w	v
s	z
ch	kh
tz	ts
tsch	ch
sch	sh
schtsch	shch
ja	ya
ju	yu

TENTATIVE CONTENTS FOR THE JULY 1961 ISSUE

ALKALIC PEGMATITES OF THE AFRIKANDA MASSIF[1]

by

E.A. Bagdasarov[2]

• translated by Royer and Roger, Inc. •

ABSTRACT

Paragenetic sequences observed in ore-bearing and barren pegmatites associated with alkalic ultramafic rocks are described. The Afrikanda massif is located in the western part of the Kola peninsula and is represented by nepheline pyroxenite. In its central part are ore-bearing pegmatites containing concentrations of titanomagnetite, knopite, schorlomite garnet, nepheline, pyroxene, and phlogopite. Processes of replacement are described and a comparison is made of geochemical features of these pegmatites as compared to granitic pegmatites, nepheline syenite pegmatites, and gabbroic pegmatites. --M. Russell.

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INTRODUCTION

Alkalic pegmatites associated with a complex of ultrabasic and alkalic rocks are somewhat rare. In the U. S. S. R., they are known only on the Kola Peninsula and in the north of the Siberian platform.

Mineralogically and geochemically, the alkalic pegmatites of the Afrikanda massif are unique and of particular interest. This article, based on material by the author and in part by A. A. Kukharenko, gives a general description of pegmatites, distinguishes the types of pegmatites, their geologic interrelations, interactions with surrounding rocks, mineralogic features, geochemistry and processes of replacement.

The Afrikanda massif is located in the southwest part of the Kola Peninsula near the Afrikanda railroad station on the Kirov line. It was discovered in 1917 by N. G. Kassin and then systematically studied by a number of investigators and in particular detail by V. A. Afanas'yev (1936), B. M. Kupletskiy (1937, 1938), P. N. Chirvinskiy, M. S. Afanas'yev and Z. G. Ushakova (1938-1940), M. L. Lur'ya and A. A. Kukharenko (1939), and M. S. Afanas'yev (1951). Afrikanda mineralogy, including the pegmatites, has been studied by V. N. Florovskaya (1940) and A. A. Kukharenko (1941, 1949, 1952, 1958). The alkalic pegmatites were studied in greater detail by the author during 1956 and 1957.

ALKALIC PEGMATITES IN THE HISTORY OF THE GEOLOGIC FORMATION OF THE MASSIF, THEIR TYPES AND COMPOSITION

Occupying an area of approximately 7 square kilometers, the Afrikanda massif is an asymmetrical funnel-shaped mass with its axis inclined to the north. The rocks surrounding the intrusion are Precambrian biotitic gneiss changing to fenite in direct contact with the massif.

The peripheral portion of the massif consists of nephelinic pyroxenite, partly melteigite, forming in plan an open ring with a maximum width of 500 meters. Toward the center of the massif this gradually gives way to fine-grained and then coarse-grained ore-bearing pyroxenite. The pyroxenite is characterized by irregular distribution of ore-bearing minerals and the presence of streaky and veiny ores of titanomagnetitic-knopitic composition. The central portion of the massif is an igneous breccia of ore-bearing olivinite with pyroxenite as a cement.

A. A. Kukharenko distinguishes three principal stages or intrusive phases in the history of formation of the massif. The first stage consists of the intrusion and crystallization of olivinite, forming a fissured intrusion with a northeasterly strike. In the second stage (the main stage) the intrusion of pyroxenite magma occurred. Intrusion of the pyroxenite was accompanied by disintegration of the olivinite, its partial assimilation, and the formation of igneous breccia in the central field of the massif.

According to A. A. Kukharenko, the process of crystallization of the pyroxenite was accompanied by diffusion differentiation: by migration of alkalis to the intrusion contacts and by concentrations of low-mobility iron-titanium complexes in the central part of the massif. This explains the zonal structure of the intrusion (the formation of nephelinic pyroxenite and melteigite joined in one common ring of the

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[1]Translated from Shchelochiye pegmatity massiva Afrikanda: Zapiski Vsesoyuznogo Mineralogicheskogo Obshchestva, Leningrad, v. 88, no. 3, 1959, p. 261-274. Reviewed for technical content by W.T. Pecora and Michael Fleischer.

[2]All-Union Scientific Research Institute of Geology, Leningrad.

massif) and the restriction of coarse-grained ore-bearing pyroxenites to the central field of the intrusion. In the process of pyroxenite crystallization a gradual accumulation of metallic components occurred in a residual fusion, leading in the final stage of crystallization of pyroxenite to the formation of the above ores of a fusive type.

The third stage in formation of the massif was marked by intrusions of alkalic magma and the formation of numerous veins of pyroxenic-nephelinic rock and alkalic pegmatites of various composition.

Pegmatitic bodies are present only within the massif and are sholly absent in the gneisses surrounding the intrusion. Numerous excavations reveal their extremely irregular distribution, e. g., the main mass of pegmatite is found in the central portion of the massif, the zone of distribution of coarse-grained pyroxenite. Here, the pegmatite forms whole fields and pockets of variously oriented, intersecting, branching, tapering veins dissecting both the metallic pyroxenite and the olivinite blocks.

From the whole variety of pegmatite deposits there are two principal types of infusion of pegmatitic material which are clearly distinguishable: 1) injection of pegmatites along fissures or their intrusion into attenuated zones of surrounding rock with the formation of veins, lenses, tube-shaped, rod-shaped and other bodies of various thickness and extent; 2) intimate penetration of pegmatitic material in isolated portions of pyroxenite, sometimes, as it were, the impregnation of pyroxenite with alkalic pegmatitic material along the zones of granulation or surfaces of pseudo-stratification. With such injections, the large contact surface of penetrating alkalic material with ultrabasic rocks, the marked difference in composition, and the relatively high temperature caused intensive mineral transformations, leading to extensive transformation of the rocks and the occurrence of unique hybrid pegmatites (migmatitic-pegmatites). Depending on the amount of injected material and the nature of its distribution, many variations in composition, texture and structure of such hybrid pegmatites are present. These structures are also characterized by a variety of configurations and the absence of sharp boundaries with the rock surrounding the pegmatite.

Alkalic pegmatites occurring in the form of veins are characterized by a great range in mineral composition. Among these we may distinguish the following three types of veins, often accompanied by transitional phases: 1) knopitic-titanomagnetic-schorlomitic-nephelinic pegmatites; 2) pyroxenic-schorlomitic-nephelinic pegmatites; and 3) pyroxenic-nephelinic pegmatites.

On the basis of observations of veins intersection, the sequence of pegmatite formations listed in Table 1 was established. It should be mentioned that pegmatite bodies of different origin are in most cases discrete in occurrence.

Among the earliest types to occur are the metallic pegmatites, which appear in the two types of injection discussed above.

TABLE 1. Sequence of formation and composition of pegmatites

	Types of Pegmatite (Data in percent)
	Normal (spaces filled)
Metallic pegmatites	1) $\underbrace{\text{Knopite-titanomagnetite-schorlomite}}_{70-90}$-nepheline (to 30)
Nonmetallic pegmatites	2) Pyroxene (15-20)-schorlomite (10-15)-nepheline (65-75)
	3) Pyroxene (15-35)-nepheline (60-75)
	4) Nepheline
	Migmatitic (hybrid)
Metallic pegmatites	1) $\underbrace{\text{Knopite-titanomagnetite}}_{50-60}$-$\underbrace{\text{pyroxene-phlogopite}}_{40-30}$-nepheline ($\approx 10$)
Nonmetallic pegmatites	2) $\underbrace{\text{Pyroxene-nepheline}}_{60-70}$-$\underbrace{\text{knopite-titanomagnetite}}_{20-30}$-$\underbrace{\text{schorlomite-hornblende}}_{10}$
	3) Phlogopite (to 70)-$\underbrace{\text{knopite-titanomagnetite}}_{15-20}$-nepheline (to 10)
	4) --------------------

Fissure injections of ore-bearing pegmatites are distributed almost entirely in the central portion of the massif, where they occur in the form of veins, lenses, tube-shaped, and rod-shaped bodies. They are usually 0.5 to 3 meters thick, but sometimes attain thicknesses of several tens of meters (for example, in the rod-shaped body exposed in the southeast portion of the intrusion, in the so-called "ore quarry").

The mineral composition of the ore-bearing pegmatites varies widely. Their rock-forming minerals are titanomagnetite, knopite, schorlomite and nepheline; monoclinic pyroxene and apatite are of secondary importance. The first three minerals comprise a total of 70 to 90 percent by volume. Among the significant secondary minerals, some use has been found for phlogopite, chlorite, sphene, prehnite, cancrinite, natrolite, calcite, and other minerals.

In the most general case the ore-bearing pegmatite is an irregular coarsely crystalline aggregate of grains of titanomagnetite and knopite, cemented by deposits of schorlomite and nepheline or transformation products of the latter. The outer parts of pegmatitic bodies have a fine-grained structure and consist chiefly of metallic minerals.

The sequence of segregation of minerals of ore-bearing pegmatites distinguishes them somewhat from silicate rocks of the massif, which are characterized by late crystallization of ore-bearing components and the development of sideronitic textures. In view of the marked unsaturability of a pegmatitic fusion-solution in terms of silica and its supersaturability in terms of calcium, titanium, and iron, the first materials to crystallize out were the principal minerals of ore-bearing pegmatites (titanomagnetite and knopite) after which segregation of the remaining minerals (schorlomite, pyroxene, and nepheline) occurred. In the large bodies of ore-bearing pegmatites, crystallization occurred over a longer period of time and was more differentiated, apparently because of the great mass of the substance, the considerable heat reserve, and the slower cooling of the bodies. Thus, in a body of ore-bearing pegmatite exposed in the "ore quarry" it was possible to detect pockets (unusual "vypoty") consisting of segregations of schorlomite, pyroxene, nepheline, and apatite. The mineral composition of these isolated pockets coincides completely with the composition of the barren pegmatites which crystallized later.

Contact reactions of ore-bearing pegmatites and the rock veins surrounding them are quite clearly expressed. The relatively high temperature of crystallization and the chemical difference in the components of metallic pegmatites and the surrounding rock caused an intensive metasomatic reaction, leading to a substantial change in the composition of these and other materials. The interaction of most ore-bearing pegmatites with the surrounding rock was limited chiefly to the zones of immediate contact, in which there is commonly a normal zoning of metasomatic-reaction formations, reflecting the stages of the process and a change in conditions of interaction between the pegmatite and the surrounding rock.

Upon contact with ore-bearing pegmatites in the first stage, pyroxenites undergo recrystallization and replacement by knopite and titanomagnetite. This process occurred with such intensity in some places that the pyroxenites are often represented only by isolated relicts wholly buried in the ore mass. In the following stage there is a characteristic occurrence of schorlomite, forming fringes around pyroxene grains and filling their interspaces where pyroxenite is in contact with pegmatite. The last stage is characterized by the formation of a "skarn" complex of minerals (diopside, hornblende, pargasite, phlogopite, andradite, vesuvianite, clinochlore, allanite, epidote, and other minerals) developing into a diopside-augite pyroxenite. This mineral association in turn changes into a lower-temperature association of typically hydrothermal minerals (chlorite, sphene, calcite, hematite, prehnite, various zeolites, etc.).

The changes in ore-bearing pegmatites themselves in the zone of contact are reflected in a decrease in grain-size of the rocks, an increase in schorlomite content and in the appearance of phlogopite, the content of which in pegmatites decreases rapidly with distance from the contact.

The process of contact interaction of ore-bearing pegmatite and pyroxenite reactions may be reduced to reactions of exchange character which are represented schematically in Figure 1.

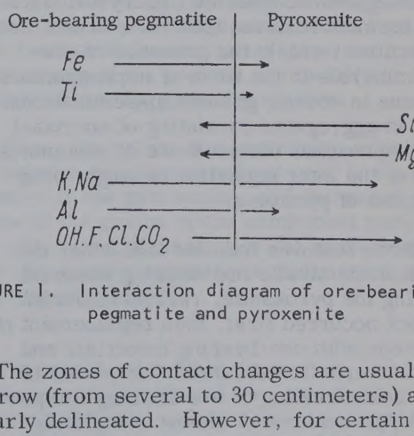


FIGURE 1. Interaction diagram of ore-bearing pegmatite and pyroxenite

The zones of contact changes are usually narrow (from several to 30 centimeters) and clearly delineated. However, for certain large bodies of ore-bearing pegmatites, these zones attain considerable thickness, their boundaries are indeterminate, and it is often difficult to

distinguish the line of separation between ore-bearing pegmatite and the surrounding coarse-grained pyroxenite.

The interaction of metallic pegmatite and olivinite is relatively weakly expressed. In the zone of contact, olivinite undergoes no substantial change, with the exception of insignificant physical disintegration, purification [leaching?] of the rock, and formation of narrow (measured in millimeters) phlogopitic and titanomagnetitic-knopitic fringes. The ore-bearing pegmatites at the zone of contact with olivinites are distinctly enriched with ore minerals.

Ore-bearing migmatite-pegmatites (hybrid pegmatites) are widely distributed in the central and southeastern portions of the massif. The most abundant of the exploited types are the nephelinic-phlogopitic-pyroxenic pegmatites, individual bodies of which are exposed over areas up to 100 by 40 meters.

The chief mass of these rocks consist of pyroxene (pyroxenite relicts and new pyroxenite), knopite, titanomagnetite, and nepheline. In addition, the nepheline and ore-bearing minerals, as it were, impregnate the pyroxenite, penetrating it in the form of fine disseminations. The new pyroxene is macrocrystalline, with unit sizes up to 10 centimeters or more, and contains great numbers of knopite inclusions and, more rarely, titanomagnetite. The interspaces between the pyroxene grains are filled with nepheline with abundant impregnations of knopite and titanomagnetite. The total quantity of ore-bearing minerals comprises up to one half the volume of the rocks under description. Isolated pockets and lens-shaped bodies consisting either of compact ores with modified nepheline or aggregates of phlogopite and ore-bearing minerals occur in the rocks.

The study of large, transparent polished sections shows that the migmatite-pegmatites have the following characteristics: recrystallization and replacement textures (poikilitic areas, lattice structures, etc.); the presence of ore-bearing minerals in the form of impregnations of pyroxene in coarse-grained disseminations and also in aggregates consisting of corroded grains of pyroxene; the presence of xenomorphic deposits of the later nepheline in larger prismatic grains of pyroxene.

The above features indicate that under the influence of the alkalic ore-bearing material penetrating the pyroxenite, recrystallization of the rock occurred first, then replacement of the pyroxene with ore-bearing materials and partly with nepheline occurred. In places of greatest concentration of ore-bearing components, the pyroxenite was almost completely replaced by knopite and titanomagnetite, and in other places the ore minerals formed a dense impregnation in the grains of recrystallized pyroxene and, along with the nepheline, filled the interspaces between its metacrystals, corroding and pitting the latter. In the last stages of mineral formation there was superimposed on this mineral association a later association which arose by replacement of the previously formed minerals (chiefly pyroxene, knopite, and nepheline). At first the characteristic "skarn" association of Ca-Mg-minerals (hornblende, phlogopite, andradite, vesuvianite, epidote, etc.) developed, and in the last stage the association of hydrothermal minerals (chlorite, sphene, zeolite, calcite, etc.) developed.

Thus, the processes leading to the formation of migmatite-pegmatites are similar to the metasomatic reaction processes developing in the endocontact and contact zones of veins of metallic pegmatites.

Barren pegmatites are extensive in the Afrikanda massif and are concentrated chiefly in its central portion. They occur chiefly as veins having various thickness and length. There are many series of pegmatite veins of similar extent, located close together. Observations show that the veins in general correspond to two principal systems of diagonal fissures in pyroxenite, having a northeasterly and northwesterly trend and sharp dips in a variety of directions, as well as a system of meridional fissures dipping sharply west and southwest.

A less widespread form of intrusion of barren pegmatites is the intimate intrusion of these pegmatites into pyroxenite, leading, as in the case described above, to the occurrence of migmatite-pegmatites.

Of the barren pegmatites occurring in the form of veins, two types are distinguished on the basis of mineralogic composition: pyroxenic-schorlomitic-nephelinic and pyroxenic-nephelinic pegmatites. The latter are of later origin and their veins commonly cross bodies of pyroxenic-schorlomitic-nephelinic pegmatites.

Pyroxenic-schorlomitic-nephelinic pegmatites are characterized by a coarsely-crystalline texture, in which, against a background of coarse-grained pegmatite, large blocks of nepheline, schorlomite, and columnar crystals of pyroxene occur. The dimensions of the pyroxene crystals are in places 40 to 60 centimeters in length, and the blocks and irregular fragments of nepheline and garnet commonly measure 25 to 30 centimeters in diameter.

Most of the pegmatitic veins do not have a zonal structure, but in isolated bodies zoning is quite clearly expressed. The bodies of such pegmatites in the "near-salband" (contact zone) part consist of fine-grained rock with the composition of ijolite. Toward the axis of the vein there is an increase in coarseness of grains, and beyond the intermediate grains the rock

changes to a large-crystal texture with the block structure of the pegmatite in the central portion of the vein. Moreover, the quantitative relationships of the minerals comprising the various zones remain approximately identical, with a certain enrichment of nepheline in the axial zone of the veins.

The chief minerals of these pegmatites, nepheline, pyroxene and schorlomite, are present in varying quantities. Calculation of the average mineralogical composition of the most typical pegmatitic veins (estimated by using a measuring rule directly at the walls of a trench) gave the following figures in percentage by volume: nepheline 65 to 75 percent, pyroxene 15 to 20 percent, schorlomite 10 to 16 percent. Knopite, titanomagnetite, hornblende, biotite, and apatite occur in lesser amounts, while ilmenite, pyrochlore, zircon, pyrite, chalcopyrite, etc., occur as minor accessory minerals. Prehnite, various zeolites, sodalite, chlorite, hematite, calcite, sphene, etc., occur among the secondary minerals.

It should be pointed out that among these pegmatites there were varieties enriched with knopite and titanomagnetite and occupying, as it were, an intermediate position in composition between that of metallic pegmatites and pyroxenic-schorlomitic-nephelinic pegmatites of the ordinary type.

The sequence of mineral formation in the pegmatites is as follows: First in the form of well-developed crystals there were the isolated ore minerals knopite and titanomagnetite, then nepheline, forming idiomorphic tabular (frequently hexagonal) crystals. Somewhat later there were isolated grains of pyroxene (diopside-augite), schorlomite and apatite; these are xenomorphic relative to nepheline and fill the intercrystal spaces of the latter and of metallic minerals.

Observations show that in some of these pegmatites there are clearly expressed indications of recrystallization. Apparently because of reaction with the products of residual crystallization, enriched by volatile components, recrystallization of the previously formed minerals and an increase in their grain size occurred. As a result of this recrystallization, pegmatites of block texture consisting chiefly of nepheline, pyroxene, and schorlomite with various admixtures of apatite and metallic minerals developed.

In the pneumatolytic-hydrothermal stage, as the result of metasomatic replacement of the previously isolated minerals, the association of minerals in the sequence listed in Table 2 developed.

The processes of replacement of the primary minerals of pegmatites are described in greater detail below.

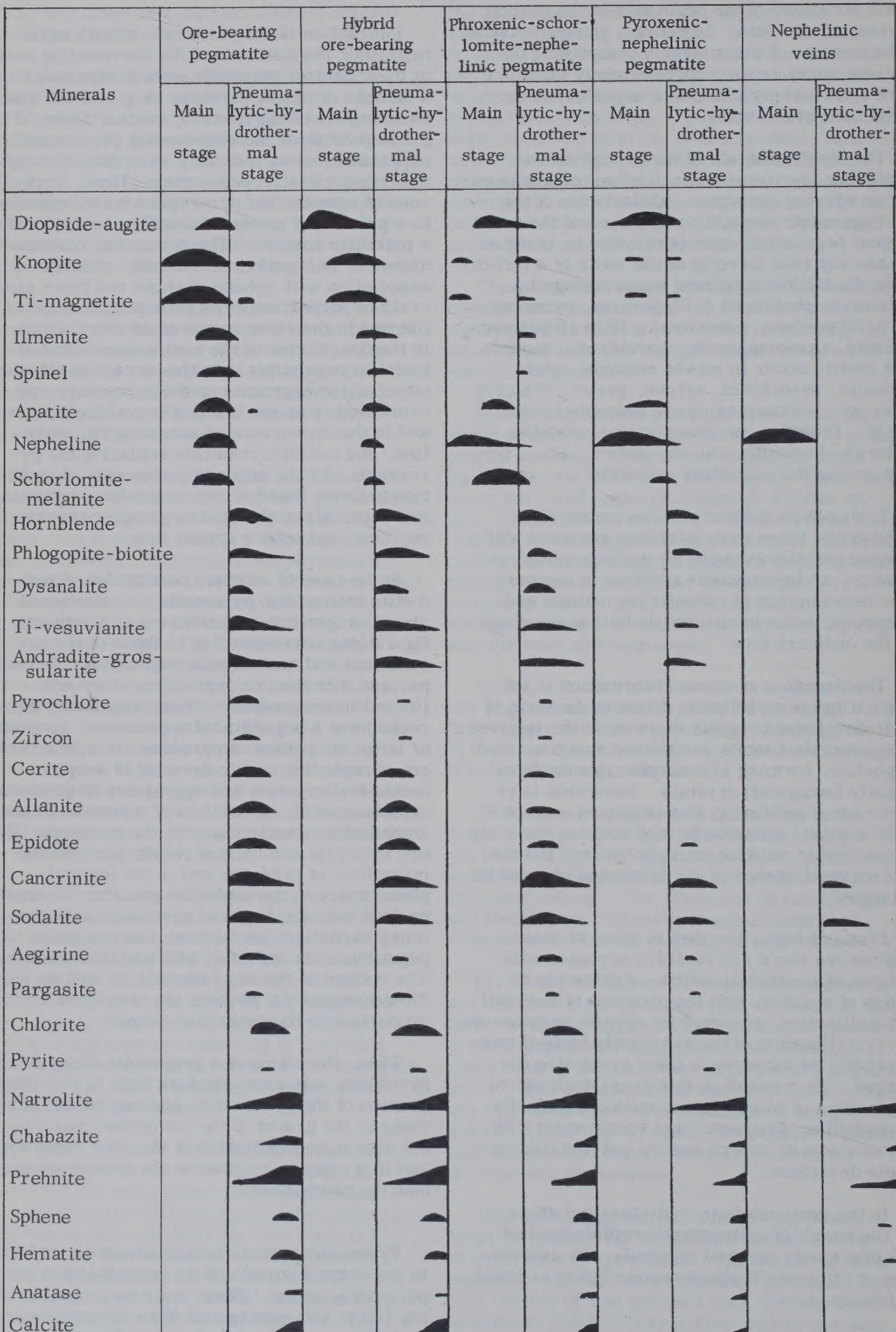
Interaction of the pyroxenic-schorlomitic-nephelinic pegmatites and the surrounding rocks at their contact is usually weakly expressed. In a number of cases, however (e. g., in the southeastern part of the massif), contact action of the pegmatite on the surrounding pyroxenite is expressed just as intensely as in the previously described metallic pegmatites. Here, in the zone of contact, the pyroxenites were subjected to a process of recrystallization and acquired a poikilitic texture. The pyroxenite contains diopside, phlogopite, hornblende, chlorite in association with sphene, calcite and other minerals in porportion to its proximity to pegmatite and in the same sequence as noted above in the description of the zoning near veins of metallic pegmatites. At the contact itself, the effect of the pegmatite on the pyroxenite was expressed in an intrusion of pegmatite matter and in the appearance of schorlomite, nepheline, and metallic minerals replacing the pyroxenite. Of the secondary minerals, in addition to those listed above, andradite, vesuvianite, minerals of the epidote group, prehnite, zeolites, and others appear here.

In the case of intimate penetration of pegmatite matter into pyroxenite, as mentioned above, migmatite-pegmatites occur with configurations corresponding to those of the pyroxenites and normal vein pegmatites. In comparison with fissure pegmatites, they are limited in occurrence. Macroscopically, these rocks have a pegmatoidal appearance, consisting of large microlites of pyroxene, irregular pockets of nepheline, cubic crystals of knopite, octahedral crystals and aggregates of grains of titanomagnetite, as well as of schorlomite and amphiboles, developing over the pyroxene. The ore minerals are located chiefly between the microlites of pyroxene and in the form of phenocrysts in the nepheline pockets. In comparison with the fissured pyroxenic-schorlomitic-nephelinic pegmatites, the migmatite-pegmatites are enriched with metallic minerals. The content of the ore minerals as well as the dimensions of the pockets are usually in direct proportion to the nepheline content.

Thus, the action of a pegmatitic injection on pyroxenite was expressed not only in recrystallization of the pyroxenite, and increased dimensions of the grains of the component minerals, but also in neutralization of the rock composition and in a certain increase in the content of ore-bearing components.

Pyroxenic-nephelinic pegmatites occur both in the central portion of the massif and in its peripheral zones. They occur as veins extending 100 to 150 meters and 40 to 50 centimeters in thickness, following the main fissure systems in the pyroxenite.

TABLE 2. Composite mineral paragenesis of Afrikanda pegmatites



The mineralogical composition of these pegmatites is rather simple. The principal minerals are pyroxene and nepheline; the secondary ones are apatite, amphibole and schorlomite. Most veins possess a pegmatoid texture. In many cases there is no regularity in the distribution of individual minerals in the body of the vein. In certain veins, columnar pockets of pyroxene, up to 10 centimeters and greater, are located perpendicular to the walls of the veins. Such an arrangement has been observed for apatite also. Isolated veins (e.g., veins of pyroxenic-nephelinic pegmatites in the northern part of the massif) have a zonal structure caused by the alternation of zoned layers enriched with pyroxene or nepheline. Both minerals, as investigation shows, crystallized at approximately the same time.

The pyroxenic-nephelinic pegmatites usually show no significant contact interaction with the surrounding rock. However, with an intimate injection of pegmatitic matter into pyroxenite, the latter becomes subject in places to the processes of phlogopitization, recrystallization, and enlargement of the grains of ore minerals it contains.

The formation of pegmatites in the Afrikanda massif was concluded by the formation of intimately intersecting veins principally, and sometimes solely, of nephelinic composition, extending both into the field of development of coarse-grained pegmatitic bodies and into the border zones of the massif. The thickness of these veins does not exceed 3 or 5 centimeters and they are usually several meters in length. The nepheline in these veins is partially replaced by aggregates of zeolite, calcite, prehnite and other secondary minerals.

Processes of Mineral Replacement

In all pegmatitic formations of Afrikanda there is evidence of metasomatic replacement of primary minerals. As observations show, these processes, occurring at various stages of development of pegmatitic veins, led to the following reactions: 1) replacement of the stronger bases by weaker bases, 2) hydration and 3) oxidation and carbonation.

Comparison of the composition of the primary minerals and the new minerals shows that the principal agents of change, in addition to a decrease in temperature, were H_2O, CO_2, O_2, Cl_2, F_2.

The processes of replacement are most clearly expressed in nepheline, monoclinic pyroxene, and schorlomite, and less clearly expressed in knopite and titanomagnetite. The sequence of changes of principal minerals of pegmatites as recorded from detailed study of systematically collected specimens, is given in Figure 2. It should be added that mineral replacement in the body of veins occurs extremely irregularly, and in isolated sections of pegmatites individual minerals often remain at different stages of change.

One of the first minerals subjected to replacement was nepheline. During the early stages of the process sodalite, natrolite and cancrinite were formed upon it. Almost simultaneously with the changes in nepheline the secondary minerals formed at the expense of the other pegmatite minerals: amphiboles, epidote, allanite, vesuvianite and biotite – from pyroxene; andradite, grossularite and allanite – from schorlomite, etc. The leading role as agents of change at this stage was played by $(OH)^{-1}$, F^{-1}, Cl^{-1} and to a lesser extent by $(CO_3)^{-2}$.

In the subsequent stages of the replacement process the role of H_2O and CO_2 increased constantly. The anion $(CO_3)^{-2}$, being stronger than that of $(SiO_4)^{-4}$, caused dissociation of silicates and the growth of minerals rich in Ca, CO_2 and H_2O: calcium zeolites (thomsonite, scoleczite, mesolite, chabazite), prehnite, calcite, etc. In the opinion of A. A. Kukharenko, the silica liberated in the process of replacement of the above mentioned silicates (particularly pyroxene, amphibole and biotite) by secondary minerals, in addition to entering into Ca-zeolites, was

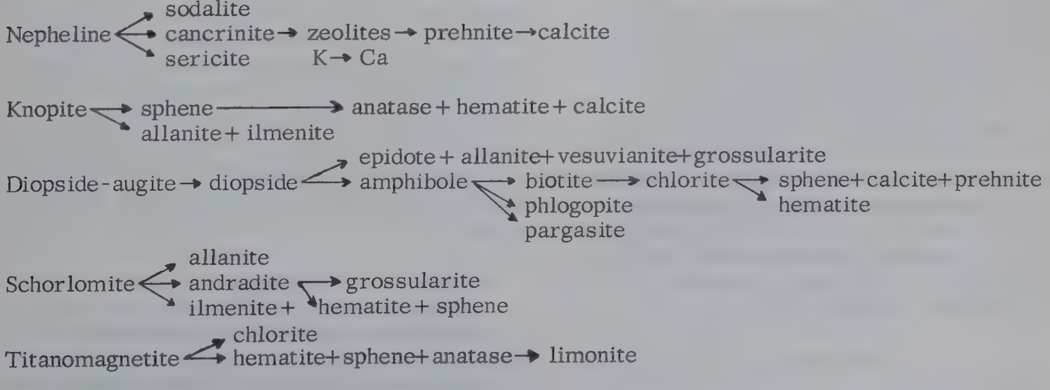


FIGURE 2. Sequence of changes in basic minerals of pegmatites

fixed in the form of sparse segregates of chalcedony and even more rarely of quartz.

The processes of carbonation and hydration occurred under oxidizing conditions. This is indicated by the presence of oxides of Fe and Ti (hematite, limonite, anatase, brookite) associated with secondary silicates and calcite.

The sequence of changes in minerals presented here is only a rough sketch and does not embrace the entire complexity and variety of metasomatic transformations of primary minerals of pegmatites. Thus, the replacement of diopside-augite by chlorite and calcite, schorlomite by sphene, nepheline by prehnite and calcite sometimes occurs immediately without intermediate stages.

Some Geochemical Peculiarities of Pegmatites

Abundance in Ti, Fe, strong bases (Na and, particularly, Ca) and marked unsaturability in Si is characteristic of the chemical nature of the Afrikanda pegmatites. This has resulted in the occurrence of a unique association of minerals — knopite, titanomagnetite, schorlomite, pyroxene, nepheline and a number of others.

On the basis of the mineralogical composition of pegmatites of various ages, the sequence of crystallization of minerals, and also on existing data concerning the chemical nature of the minerals, it is possible to comprehend the role and behavior of individual elements at various stages of development of the pegmatitic process.

The chief pegmatite elements which determined the course of mineral formation were Ca, Mg, Fe, Ti, Al, Si, Na, O, H.

Calcium

The principal mass of Ca is concentrated in metallic pegmatites where this element is fixed in knopite, schorlomite, pyroxene, apatite, and other minerals. In younger pegmatites the Ca content decreases rapidly and reaches a minimum in the later, principally nephelinic, veins. In pneumatolytic-hydrothermal formations a certain enrichment with calcium took place, caused not only by extraction of this element from silicates of the rock surrounding the pegmatites but also, apparently, by the addition of calcium by hydrothermal solutions. With this is associated the formation chiefly of the calcium minerals characteristic of the hydrothermal stage of pegmatites (prehnite, calcite, calcium zeolites, etc.).

Magnesium

In the processes of mineral formation Mg played an insignificant role compared to Ca, but its behavior on the whole is similar to that of calcium. In the initial stages both elements enter into the lattice of diopside-augite, schorlomite, and amphiboles. Mg is fixed also in small quantities in knopite and titanomagnetite. In the subsequent stages of development of pegmatites, the geochemical progress of Mg and Ca prove to be different. During the hydrothermal metasomatic replacement of pegmatite minerals Mg was concentrated in phlogopite, biotite and chlorites, whereas Ca was concentrated in hydrous aluminum silicates and carbonate. On the whole, in comparison with Ca, Mg behaves as a more mobile element in the hydrothermal stage, as is indicated by the almost complete disappearance of magnesium in the most recent hydrothermal formations.

Iron

The principal mass of Fe is concentrated in ore-bearing pegmatites, wherein this metal is the chief constituent of titanomagnetite and enters substantially into the pyroxene and schorlomite lattice, and to a lesser degree in knopite. In the younger pegmatites, the Fe content decreases sharply. In the hydrothermal stage of pegmatite formation iron is partially fixed in biotite, phlogopite, chlorite, hematite and limonite. The main mass of this element is carried away.

Titanium

This element, most characteristic of the Afrikanda pegmatites, is concentrated chiefly in ore-bearing pegmatites in the form of knopite, titanomagnetite, ilmenite, schorlomite, and to a lesser degree in pyroxene (where the TiO_2 content reaches 2 percent and greater). Particularly high local concentrations of Ti are characteristic of certain hybrid ore-bearing pegmatites formed by interaction of pegmatitic material with surrounding ore-bearing pyroxenite. The Ti content decreases sharply in the younger pyroxenic-schorlomitic-nephelinic and pyroxenic-nephelinic pegmatites. In the hydrothermal stage of pegmatite formation Ti, possessing negligible mobility, enters into the lattice of a large number of minerals —titanium-vesuvianite (to 5 percent), chlorite and biotite (to 3 percent), sphene, anatase, brookite, andradite, epidote, etc. It should be noted, however, that in areas of more intensive hydrothermal conversion of pegmatites titanium minerals, as a rule, are lacking, thus attesting to the known mobility of this element and its removal.

Aluminum

In the earlier pegmatites Al is fixed in nepheline, schorlomite, diopside-augite, and in small amounts in knopite and titanomagnetite. The Al content in later pegmatites gradually

rises, in association with the increase in the amount of nepheline in them, and reaches a maximum in veins consisting chiefly of nepheline. In the later stages, in the transformation of primary aluminum-bearing minerals, Al behaves as an inert component and is fixed in many new mineral formations — in biotite, chlorite, grossularite, vesuvianite, prehnite, zeolites, gibbsite, and other minerals.

Silicon

In the course of development of the pegmatitic process there is a gradual increase in the silicon content from ore-bearing pegmatites, (consisting of almost half metallic minerals not containing Si) to pyroxenic-schorlomitic-nephelinic pegmatites and further to pyroxenic-nephelinic pegmatites; only in the latest nephelinic veins is the Si content slightly lower. During metasomatic conversion of pegmatites the behavior of Si is complex.

In the highest-temperature pneumatolytic-hydrothermal stage the Si released from pyroxene during its phlogopitization and amphibolization does not enter into the lattice of any newly formed minerals of pegmatite but behaves as a mobile element. In the hydrothermal stage, Si is only slightly mobile and is fixed not only in the aluminum silicates, which are richer in silica (prehnite, natrolite, etc.) than nepheline, but is also isolated in the form of free silica.

Sodium

In pegmatites, Na is concentrated chiefly in nepheline. The Na content in other minerals (pyroxene, hornblende) is not great. Playing an insignificant role in the early metallic pegmatites, Na is gradually accumulated in the younger formations and its content reaches a maximum in the later nephelinic veins. In the hydrothermal stage, during intensive calcium metasomatism, the main mass of Na migrated beyond the limits of the pegmatites and only an insignificant part of it was fixed in the lattice of calcium-sodium zeolites.

Rare Elements

Regularites are detected also in the behavior of certain rare elements in the alkalic pegmatites of Afrikanda — Nb, Ta, Tr, Zr, Sr, Th, and others. The main mass of rare elements was concentrated in metallic pegmatites, as an isomorphous impurity in such minerals as knopite, schorlomite, sphene and apatite. The entry of the rare elements into the crystal structure of the above minerals contributed to a considerable degree to the relatively high temperature of crystallization of the ore-bearing pegmatites. However, the relative concentration of rare elements in minerals of later pegmatites increased sharply. Thus, in knopites of the latest generations in the greatest concentrations of rare earths occurred, whereas in the knopites of ore-bearing pegmatites the concentration is only half as great. A similar condition occurred in certain other minerals containing rare earths, e. g., apatite and sphene.

Nb and Ta, as a result of geochemical behavior similar to Ti, are concentrated chiefly in minerals of the last stage — in knopite, sphene, schorlomite, and partly in titanomagnetite. Their concentration in these minerals of the later pegmatites is increased more than tenfold.

The high relative concentration in minerals of late pegmatites is as follows: for Zr in schorlomite and pyroxene; Sr in apatite, sphene, and schorlomite; Sc in amphibole, pyroxene, and schorlomite.

Favorable conditions were created for accumulation of a number of rare elements, liberated from the previously disintegrated primary minerals of pegmatite, in the pneumatolytic hydrothermal stage of pegmatite development during recrystallization and replacement of the earlier minerals. In this stage the local concentration of rare elements led to the development of independent minerals containing Nb, Zr, Tr (dysanalite and pyrochlore, zircon and zirkelite,cerite and allanite).

The above basic regularities in mineral formation in the alkaline pegmatites of Afrikanda, as well as the behavior of individual elements, are summarized in a paragenetic diagram (table 2) and in Table 3 in which we list a comparison of alkalic pegmatites of Afrikanda with other types of pegmatites. As is seen from Table 3, the Afrikanda pegmatites occupy an intermediate position between apatitic alkalic pegmatites and the pegmatites of gabbroid magmas. In the last pegmatites of Afrikanda Ti, Fe, Mg, Ca and P began to play a significant role and in the alkalic pegmatites their position followed that of Sr, Zr and Tr.

CONCLUSIONS

The following conclusions may be drawn:

1. There is a close spatial and genetic relationship between the alkalic pegmatites of Afrikanda (particularly their early types) and the rocks of the first two intrusive stages. All these formations belong to one genetic group, the complex of ultrabasic alkalic rocks.

2. In the process of crystallization of the main rocks of the intrusion (pyroxenite), the excess of strong bases (with the marked unsaturability of SiO_2 magma) caused transference of a considerable part of the Fe, Ti, Na, K, Ca and Al from the main phase of crystallization to the residual phase. The alkaline

TABLE 3. Elements in various pegmatites

Granitic pegmatites*	Nepheline-syenitic pegmatites	Gabbroid pegmatites	Afrikanda pegmatites
(Ca little), (Sr), (Ba none)	Sr ≫ Ba ≫ Ca	Ca ≫ Sr and Ba very little	Ca ≫ Sr, (Ba very little)
P, (Zr), Hf	P, Zr, (Hf)	P, (Zr very little)	P, Zr, (Hf)
FeO > Fe_2O_3	Fe_2O_3 > FeO	Fe_2O_3 > FeO	Fe_2O_3 > FeO
Ta ≫ Nb	Nb > Ta	Nb > Ta	Nb ≫ Ta
Y-group (Gd)	Ce-group (La, Ce, Pr, Nd, Sm, Eu)	(Ce-group)	Ce-group
F > B ≫ Cl	(B), CO_2, S, Cl (F)	(CO_2, S, Cl, F)	CO_2, H_2O, F, Cl (S)
F > Cl	Cl > F	Cl > F (very little)	F > Cl
K > Na	Na > K	Na > K (very little)	Na > K
U > Th	Th > U	Traces	Th > U
Li ≫ Cs, Rb, Be	Almost no Li, Be sparse	No Li and Be	Almost no Li, Be sparse
Almost no V	V present	V sparse	V sparse
Ti little, Mo	Ti very much, Mo	Ti very much	Ti very much, Mo none
Fe little	Fe much	Fe very much	Fe very much
O scarce, S little	O more (beyond stage of oxidation)	O more	O more
W, Mo	W little, Mo none	No W and Mo	No W and Mo
Si ≫ Al	-	-	-

* After A. Ye. Fersman (1940).

pegmatites owed their very origin to this residual ore-bearing alkalic differentiation occurring in the deeper portions of the pyroxenic intrusion.

3. Periodic tectonic stresses accompanied by splitting of the surrounding rocks caused the variable nature of egress of the products of residual crystallization and led to the formation of a series of alkalic pegmatites of various ages differing from one another in spatial location, distinctive material composition, texture, and structure.

4. There is clear evidence of two forms of injection of pegmatitic material: a) fissure injection (filling of empty spaces); b) injection of the migmatitic type. The character and intensity of contact processes associated with age differences of pegmatites vary in time and apparently depend on the composition and temperature of the introduced pegmatitic material. If contact action (of the early metallic pegmatites) on pyroxenite in the initial stages was manifested in recrystallization and replacement of pyroxenite by titanomagnetite and knopite, then the stages of highest temperature in contact-reaction zones of the later pegmatites gave rise chiefly to schorlomite and then hornblende and phlogopite. The latest pegmatites, as a rule, had no contact action on the surrounding rock.

5. All the various pegmatitic formations of Afrikanda were caused by a change in composition of pegmatitic material with time and by the difference in nature of its injection.

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REMARKS ON THE GENETIC SIGNIFICANCE OF CERTAIN TYPES OF HARD MINERAL INCLUSIONS IN QUARTZ[1]

by

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• translated by Royer and Roger, Inc. •

ABSTRACT

Syngenetic and protogenetic hard mineral inclusions are met with in crystals of quartz. Syngenetic inclusions are of special interest for the determination of some important details in the mechanism of crystal growth and the elucidation of the composition and concentration of quartz-forming solutions. Protogenetic inclusions facilitate the forming of conclusions on the regime of solutions, the conditions of growth of crystals, etc. For instance, a study of the "hairstone" (crystals of quartz with numerous accumulations of fine needles of tourmaline, rutile, etc.) suggest that rock crystals often grow in open cavities in very tranquil conditions, probably, mainly as a result of a diffusion of the substance. The presence of "intercrystal druses" of quartz in quartz may witness a pulsating intake of solutions and the absence of an equilibrium in the latter. The study of some inclusions suggests a possible formation of crystals of rock crystal resulting from a recrystallization of the enclosing rocks (quartzites). So-called powderings which have repeatedly been described and which are widespread in nature, evidently originate in consequence of various processes and can belong to the group of syngenetic inclusions. --Auth. English summary.

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In the years after World War II, in both Soviet and foreign geological literature, many papers have appeared that describe inclusions in minerals and consider their significance in the genesis of both deposits of minerals and the minerals themselves in which these inclusions occur. Particular attention has been devoted to the analysis of inclusions containing mineral-forming solutions. Numerous publications by N. P. Yermakov, not to mention papers by G. G. Grushkin, A. I. Zakharenko, G. G. Lemmleyn, V. F. Lesnyak and many others, have indicated the great possibilities presented by the mineral-thermometric method of studying liquid and gaseous inclusions. In these investigations, however, insufficient attention has been paid to solid mineral inclusions. On the other hand, D. P. Grigor'yev quite some time ago called attention to the fact that mineral inclusions, especially the so-called powders, are of considerable interest and may be used as "mineralogical levels and plumb lines", "paleoseismograms" and indications of the order of formation of the minerals and the mechanism of their genesis (Grigor'yev, 1946). Thereafter this researcher repeatedly returned to the problem of the genetic significance of certain mineral inclusions in crystals (Grigor'yev, 1947, 1949, 1951).

The present writer has deemed it useful to make a brief examination of certain types of solid mineral inclusions in quartz, which he was obliged to touch upon in his study of crystal-bearing quartz veins. He believes that his observations are of definite interest and deserve some consideration, inasmuch as they shed light on some important details of the process of mineral formation.

All the minerals that form hard inclusion in quartz may be divided into two groups: a) protogenetic, originating before the formation of the quartz crystals, and b) syngenetic, arising at the same time as the latter. These inclusions occur in various interrelationships with the host-mineral, so that they cannot always be reliably assigned to one group of the other. Nevertheless a correct diagnosis of these inclusions is always extremely important in drawing many conclusions regarding features of the process of mineral formation.

One of the most frequently occurring cases of mineral inclusions in crystals is that of the so-called powders. Powders are formed by the settling of fragments of earlier formed minerals on the upward-turned faces of the growing crystal. They thus cover the surfaces of certain crystal faces, or else are preserved at some depth within the body of the crystal as a result of the later growth of the crystal's substance.

Various investigators have suggested different explanations for the formation of the powders. D. P. Grigor'yev (1946) sees them as peculiar "paleoseismograms" that "fix the instant of shattering and crumbling of the crystals", whereas D. S. Korzhinskiy (1950) believes that the powders in buried crystalline aggregates are formed by the precipitation in the growing crystal of flakes of "less soluble

[1] Translated from Zamechaniya o geneticheskom znachenii nekotorykh tilov tverdykh mineral'nykh vklyucheniy v kvartse: Mineralogicheskiy sbornik L'vovskogo Geologicheskogo Obshchestva, 1958, no. 12, p. 106-115.

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minerals freed in the general solution of the host rocks". Investigation of certain crystals shows that both suggested mechanisms of the formation of powders evidently occur in nature.

The present writer has frequently observed in crystals of quartz irregular shaped flakes of chlorite and their accumulations, which have a fine-aggregate structure. The chlorite is variously and irregularly distributed in the body of the crystal, usually in various parts and at different depths within it, although cases have been encountered in which the chlorite is more or less uniformly distributed in certain growth zones of the quartz crystal. It may be thought that such inclusions have appeared in the quartz as a result of the sporadic settlement on the faces of the growing crystal of chlorite particles freed from the surrounding rock in the partial dissolution of this rock. Hence these powders probably arise in the manner explained by D. S. Korzhinskiy.

Very often, however, the powders are formed of chlorite which has more or less regular crystal outlines. In such cases one may agree with A. G. Betekhtin (1953), who considers that the regular hexahedral shape of the chlorite particles is inconsistent with the mechanism suggested by D. S. Korzhinskiy. It must be added that the particles of chlorite, micaceous hematite, kaolin, sericite, tiny quartz fragments and other minerals often uniformly cover different faces of the quartz crystal, thus forming very thin zones of powder inclusions. Sometimes in the surficial parts of the quartz crystal, which have a total thickness of 2-2.5 mm, one may count more than ten such zones. Such observations are also very hard to reconcile with the mechanism of powder formation suggested by D. S. Korzhinskiy. In all likelihood, powders of this nature are formed as a result of the breaking away of the crystal from the walls of the cavity and fix the moment of fracturing, as D. P. Grigor'yev supposes.

But even this mechanism of the formation of powders fails to explain all the cases observed in nature. One of the most important indications, usually cited as proof of the formation of mineral inclusions in the form of powders, is the irregular, "broken" outlines of the mineral units that have settled on the crystal faces. The presence of such "fragments", along with their disposition on one, or more often several, faces of the host crystal, is frequently sufficient basis for the conclusion not only that the crystal grew in a definite position, but that there was a "paleoseismic" regime in the process of the mineral's formation. Observations, however, show that inclusions of irregular shape and fragmental outlines, as it were, are apparently often syngenetic with the host mineral and arise in the later stages of its growth, although the proof that the accompanying mineral was formed in such a manner frequently involves great difficulties. The complex manifestation of the genesis of such inclusions is due above all to the insufficient number of indications of the simultaneous growth of minerals.

A well known indication of the syngenesis of minerals, used widely by mineralogists as a reliable criterion, is the surface of simultaneous growth with small induction faces (Shafranovskiy, 1948). But this is applicable only when the accompanying mineral is sufficiently large that the surfaces of simultaneous growth can be distinguished from the surfaces of separation between the minerals, which may fall upon the faces of the growing crystal from the walls of the crystallization cavity and will then, in N. P. Yermakov's words (1950), be the mineral forerunners. Moreover simultaneous growth of the crystals may continue for only a very short time, when the accompanying mineral grows at a much faster rate. As a result the surfaces of simultaneous growth will be strikingly undeveloped, as occurs characteristically, for example, in the case of the fluorite inclusions in rock crystal in certain deposits of the Aldan.

All these circumstances have forced the writer to seek additional criteria of the simultaneous growth of minerals, and have led to several unexpected conclusions regarding the mechanism of formation of certain "powders".

In studying the abundant inclusions of micaceous hematite in quartz crystals from the veins of the Kholodnyy and Oen deposits and Mount Dobraya in the Aldan region, it was noticed that the hematite is sometimes preserved on opposite faces of the prism, and in some crystals on all faces of the prism (fig. 1). This fact cannot be explained by the effect of gravity, or by the formation of powders or the growth of nuclei settling on the upward-turned faces of the growing quartz crystals. The inclusions are usually located in one growth zone, and in the overwhelming majority of cases in the zone close to the crystal face or the very surface layer itself. This testifies that they were formed in the very last stages of the crystal's growth. It is interesting that such inclusions are almost never encountered in crystals from cavities that produce any considerable amount of high-grade ore, whereas in pockets and nodules with lower quality quartz they occur fairly often. It was also completely unexpected that the shapes of these inclusions were irregular, the crystals had the appearance of broken fragments, and in the aggregate created the illusion of being a powder.

The formation of inclusions of such a form may be explained as follows. In the last stages of growth of the quartz crystals, the solutions were enriched with iron compounds, which gave rise to seeds of hematite crystals adhering to all the faces of the growing quartz crystal. During this time the solutions did not bear sufficient

FIGURE 1. Pseudo-powdery hematite in quartz (the crystal has been photographed in three positions, each produced by a rotation of 120° about the principal axis)

silica for the formation of complete outer faces of the quartz crystal in the growth of the last layer of its substance, so that the outermost zones of the quartz crystal grew together with the hematite, forming surfaces of simultaneous growth with it. As a result the accompanying mineral crystals, whose bases are the faces of the host crystal, have irregular outlines "in plan view", creating the impression that they are not crystals growing on the faces of the quartz crystal, but fragments torn from the place of their original attachement on the walls of the cavity in which the crystallization took place. A similar picture appears, although less clearly, in the case of the chlorite inclusions and in the Kholodnyy deposit.

In addition, in the crystal-bearing veins of Mount Dobraya the writer has found crystals of quartz whose outer zone, some 2 mm thick, was filled with very fine, but fairly large flakes of micaceous hematite (fig. 2). These hematite crystals are of irregular shapes, and their disposition shows no sign of predominant orientation (fig. 3). It is very likely that in this case,

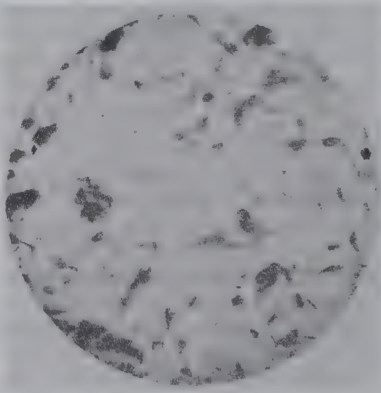

FIGURE 3. A part of the crystal shown in Figure 2, photographed through a binocular magnifying lens

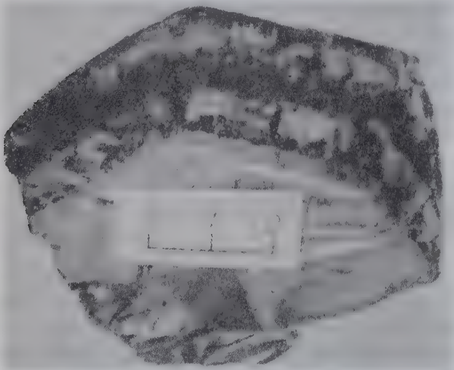

FIGURE 2. Inclusions of hematite in the outer growth zone of a quartz crystal

too, there was a simultaneous growth of quartz and hematite, the quartz-forming solutions being highly saturated with iron during the last stages in the formation of the quartz crystal.

Such observations compel one to use great caution in referring to "powders", and additional facts are required for a reliable identification of the latter. The criteria by which mineral inclusions are placed in the category of powders, besides those mentioned above, may include the presence of fragments of various minerals within the powder, sharp differences in the magnitude of the fragments, and lack of uniformity in the thickness of the layer containing them.

Thus the mineral inclusions in quartz that

are usually called powders may have different origins. Some of these pseudopowders are undoubtedly of syngenetic formation, and thus reveal the changes in the composition and nature of the mineral-forming solutions during the terminal stages in the crystallization of the quartz. The others, being true powders, belong to the group of protogenetic inclusions and may act as "mineralogical levels and plumb lines" and "paleoseismograms".

As stated above, the powders and pseudopowders are usually located in the outer zones of the crystal and are formed in the last stages of its growth. Moreover in certain deposits solid mineral inclusions in the form of euhedral crystals are also observed at some distance from the surfaces of the quartz crystals that enclose them. Some of these are protogenetic, and bear no relation to the growth of the quartz; such inclusions are of little interest. But among them one also encounters some which have grown simultaneously with the quartz crystal and are therefore of considerable interest, particularly for their indications of the composition of the mineral-forming solutions.

In establishing the syngenesis of these inclusions with the host mineral, one must deal with the same difficulties mentioned above in connection with the powders. In certain cases, however, these difficulties can be circumvented. One method of establishing the simultaneous growth of the inclusions and the host crystal consists in a thermometric study of the liquid inclusions both in the accompanying mineral and in the growth zone of the host mineral with which they are associated. Close correspondence between the homogenization temperatures of these inclusions evidently testifies to the syngenesis of the inclusions and enables us to make reliable statements about the composition of the solutions.

Interesting data on this matter were obtained by L. I. Koltun (1953) [Not in references], in his study of quartz-fluorite pairs in the quartz of the Aldan deposits. Here, in the growth zone with which the fluorite crystals were associated, he discovered primary inclusions whose homogenization temperature was equal to that of the inclusions in the fluorite. This suggests that within a definite period of time, during which the fluorite originated, the quartz-forming solutions were enriched with calcium and fluorine. This conclusion is particularly interesting in the light of the fact that direct analysis of aqueous extracts from the inclusions in the Aldan quartzes did not indicate the presence of fluorine in the quartz-forming solutions (Vul'chin, 1953).

Pyrite is often encountered as a solid inclusion in quartz — this is the only one of the sulfides included among the chief minerals in the crystal-bearing quartz veins (Laz'ko, 1956). The pyrite crystals have various sizes and occur in various relationships to the quartz crystals that contain them, but in most cases are crystallized as cubes or pyritohedra, frequently in combination with other forms.

Very interesting relationships between the members of the quartz-pyrite pairs, leaving no doubt of their syngenesis, have been discovered in a number of deposits of the Southern Urals and the Dzhezkazgan-Ulutau crystal-bearing region in Central Kazakhstan. Here the pyrite crystals are usually associated with growth zones in the quartz crystals and often occur as regular half-pyritohedra (fig. 4), which may sometimes be quite large. The induction

FIGURE 4. Pyrite crystals in quartz, forming half-pyritohedra

face of the pyrite, which frequently lies against a face of one of the quartz rhombohedra, is most often step-wise (fig. 5), but completely smooth, mirror-like faces (fig. 6) are also encountered; these are hypertrophic cube faces (verbal communication from N. I. Myaz'). It is interesting that such quartz-pyrite interrelationships are not confined to crystal-bearing quartz veins, since they have been described by G. G. Grushkin in the Aurakhmat deposit as well (Grushkin, 1948).

Determination of the causes of these very curious crystal forms requires special crystallographic and mineralogical investigations, but the presence of one of them is already of use in

FIGURE 5. Step-wise induction faces of pyrite in quartz

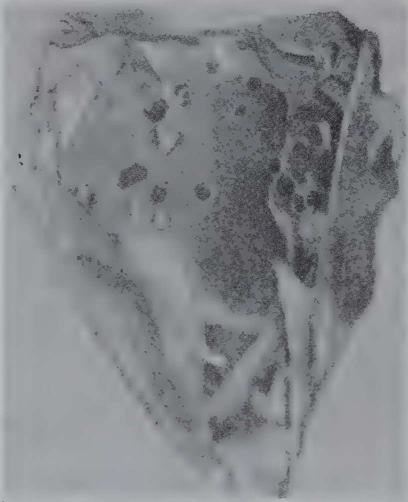

FIGURE 6. Smooth induction faces of pyrite in quartz

determining the precise composition of the quartz-forming solutions. In particular, pyrite crystals syngenetic with the quartz testify to the presence of iron and of considerable concentrations of sulfur in the solutions (Betekhtin, 1949).

It is to be noted that in most cases the formation of noticeable quantities of pyrite crystals excludes the possibility of the occurrence of any significant concentrations of hematite in the crystal-bearing cavities, and vice versa. One may list a great number of deposits, and even whole crystal-bearing regions, that are characterized by the presence in the quartz crystals of either hematite (many deposits in the Upper Aldan crystal-bearing region) or pyrite (a number of deposits) in the Urals and the western part of Central Kazakhstan). A detailed investigation of the causes of this recurrent distribution, which is very likely owing to different regimes of sulfur and oxygen (Betekhtin, 1949) in the quartz-forming solutions, would be of interest but lies outside the scope of the present article.

Apart from the types of inclusions considered above, quartz crystals are frequently found to contain protogenetic minerals in the form of acicular inclusions greatly elongated in one direction. These are often concentrated in parallel or sheaf-like bundles, or else form intracrystalline druses and other aggregates, giving the host crystal a very peculiar appearance. Particularly striking are the quartz crystals that contain growths of very fine acicular inclusions of rutile, actinolite and tremolite, tourmaline and — less often — other minerals. Such crystals are well known in mineralogy as "hairstones".

Careful examination of these "hairstones" will, in the majority of cases, show that the bases of the sheaf-like bundles of acicular mineral inclusions usually point toward the uneven surface of the host crystal, which is its surface of separation from the enclosing rock (fig. 7). The greater part of the individual growing acic-

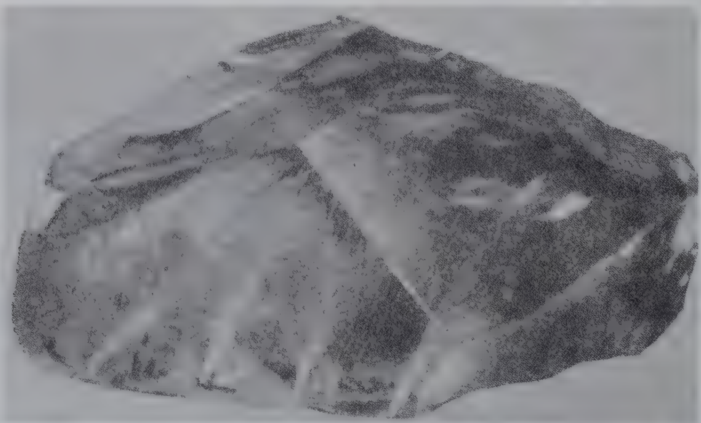

FIGURE 7. Sheaf-like aggregates of rutile in quartz

llar crystal units also have one of their ends pointing toward the surface of the crystal. This disposition of the inclusions suggests that the individual crystals and their aggregates originally were growing on the walls of the crystal-bearing cavity, and were later incorporated into the quartz crystal in the course of the latter's growth. In a thorough examination of fairly well preserved crystal cavities, one may sometimes distinguish on the walls, in situ, little brushes, bundles and minute nodules of a number of minerals in various stages of preservation. These observations confirm the order of succession in the formation of the inclusions and the host crystal, as described above.

The existence of "hairstones" leaves no room for doubt that the inclusions themselves, like the crystals that enclose them, originated under conditions of free growth in open cavities filled with solutions.

The disposition of the linear, elongated inclusions frequently shows a single orientation (fig. 8). In other cases, in the seemingly disordered tangle of needles forming the sheaf-like bundle one may also discern a regularity in the arrangement of these very fine hair-like inclusions, which are often slightly bent in one direction, independently of the place of attachment of the bases of their sheaf-like aggregates (see fig. 7). Such very fine aggregates, whose individual units are no more than the hundredth part of a millimeter in thickness, can have grown only under very quiet conditions. The inclination of the acicular inclusions in one direction is easily explained by the effect of gravity in a stable and almost immobile solution, and their undisturbed preservation in the quartz crystals by the growth of the latter through diffusion of the substance or through very weak convection currents.

In crystals of quartz one also encounters miniature druses containing beautifully formed tiny crystals of quartz (fig. 9). Some of the units of these "intracrystalline druses" sometimes even have clearly distinguishable semihedral faces and bear no trace of dissolution. Such a relationship between the host crystal and the "intracrystalline druses" probably indicates a lack of equilibrium in the solution, since otherwise the growth of the large quartz crystal would have been accompanied by the solution of the smaller ones. The growth of the large crystal of quartz, like that of the tiny crystals in the "intracrystalline druse", which often forms earlier nuclei (Grigor'yev, 1949), is evidently the result of successive intakes of new portions of the solutions into the crystal-forming cavity.

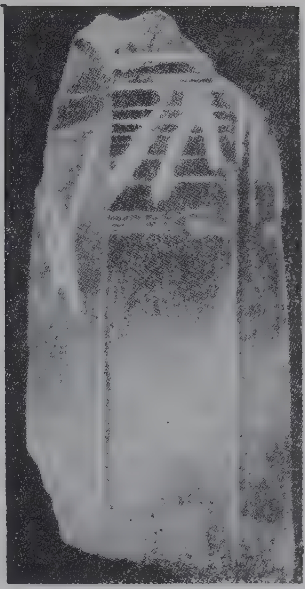

FIGURE 9. "Intracrystal druse" of quartz in quartz

Most of the facts cited above on the interrelationships between inclusions and the quartz

FIGURE 8. Parallel-oriented aggregates of tourmaline in quartz

crystals that contain them suggest that these crystals were formed by free growth on the walls of the crystal-bearing cavity. Sometimes, however, the solid mineral inclusions indicate another mechanism of growth of the quartz crystals. In certain deposits in the Polar regions of the Urals, especially the Pyramid deposit, crystals have been found which contain numerous parallel flakes of sericite and their aggregations, whose orientation corresponds fully to that of the sericite in the enclosing sericite quartzites. A. Ye. Karyakin, who first described quartz crystals with such inclusions, believes that "the quartz crystals were formed from the material of the enclosing rock and grew by replacement of its substance" (Karyakin, 1954). His article contains another formulation as well: "... many quartz crystals in the crystal-bearing zone have a zonal structure that results from the linear disposition of the sericite flakes and is undoubtedly inherited from the metasomatically replaced — or, more precisely, recrystallized — sericite quartzites."

As these quotations show, A. Ye. Karyakin explains the vestiges of the host rock observed by him in the quartz crystals by a metasomatic replacement or recrystallization of the quartzites. It appears to this writer, however, that here, as in other cases of the formation of quartz crystals in crystal-bearing veins, metasomatism cannot have played any considerable role, mainly because in metasomatism of the sericite quartzites the sericite above all should be replaced by quartz, whereas it is completely or almost completely preserved in the quartz crystals.

The very specific process of recrystallization of the enclosing rocks with the formation of quartz crystals, it seems to us, could take place only under definite and favorable conditions, although in the formation of the body of the quartz veins themselves this process may have occurred quite extensively. In the Pyramid deposit the sericite quartzites surrounding the crystal-bearing cavities form a rather loose and porous rock, which during the formation of the quartz crystals, especially in the vicinity of the cavity, may have been filled with the quartz-forming solution in the manner of a sponge. For this reason, in the recrystallization of these quartzites the quartz crystals would have grown in the same way as they would in an open cavity. The best confirmation of this view is provided by the two-sided druses, whose characteristics are entirely the same in both their parts, except for the fact that the part of the druse formed within the enclosing rock is composed of crystals filled with regularly oriented sericite flakes (fig. 10). Hence such two-directional druses are a combination of growth druses and recrystallization druses (Grigor'yev, 1953), formed at the same time but under different conditions.

A feature of great importance in establishing the composition of the mineral-forming solutions and their concentrations are the polyphase inclusions that often contain some quantity of mineral-"captives" (Yermakov, 1950). This group of solid inclusions has been noted by many authors, but has been studied mainly in connection with investigations of liquid and gaseous inclusions. Nevertheless the great importance of making special and detailed investigations of mineral-"captives" may be seen from the fact that only the establishment of their presence in enormous concentrations in inclusions enabled N. P. Yermakov to come to his conclusion, which is very significant in the theory of mineralization and ore formation, regarding the exceedingly high degree of saturation of certain hydrothermal solutions with mineral substances, to the extent that these solutions might be called "hydrothermal brines" (Yermakov, 1950). The fascinating micro-universe of minerals in liquid and gaseous inclusions still awaits its investigators, since at the present time only a single paper has been devoted to it (Kalyuzhnyy, 1954).

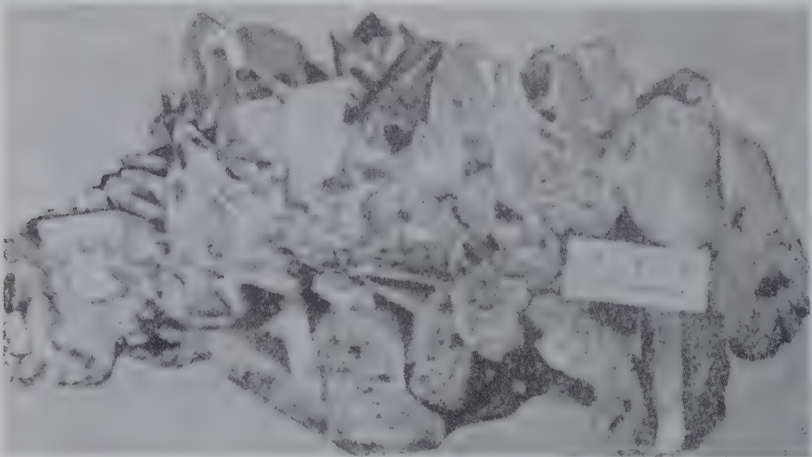

FIGURE 10. Two-directional combined druse (growth from the left and recrystallization)

Thus even a cursory examination of certain types of solid mineral inclusions shows that these are prime objects for study, and that an investigation of them may help to disclose many peculiarities of the process of mineral formation.

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FORMATION OF COAL DURING THE CRETACEOUS PERIOD AND ITS ROLE IN THE GLOBAL PROCESSES OF COAL ACCUMULATION[1]

by

V.N. Vereshchagin[2]

• translated by Eugene A. Alexandrov[3] •

ABSTRACT

P. I. Stepanov suggested that during the Cretaceous there probably took place a considerable accumulation of coal, although that time was always considered to have been a period of attenuation of coal accumulation. The analysis of facies of the Cretaceous deposits in the far east maritime region of the U. S. S. R. as well as of those of Alaska led the author to conclude that coal accumulation during the Cretaceous was tremendous. This conjecture has now been confirmed: the new estimate of coal reserves of the U. S. S. R. has shown the Cretaceous Lena coalfield to be the largest in the world. Tremendous reserves of coal are also concentrated in the Bureya, Maritime, Anadyr and Sakhalin Cretaceous coal-bearing basins of the U. S. S. R. in the Ryōseki basin of Japan and in the Cretaceous coal deposits of North America, particularly in Alaska where a major coalfield very likely exists. Thus it may now be considered that during the Cretaceous there accumulated reserves of coal comparable in immensity to those accumulated during the Tertiary and undoubtedly much larger than those of the Permian, Carboniferous and Jurassic. It may be asserted that rate of coal accumulation kept ever increasing in the course of geological time, and the Cretaceous may be regarded as a period of very intensive coal accumulation. Following up Stepanov's idea we can point out the knots of Cretaceous coal accumulation: Lena, Alaska, Anadyr, Sakhalin — Maritime. The new data on the Cretaceous coal accumulation should be taken into account in any reconstruction of the history of geological development of the earth and of the evolution of the organic world. --Author's English Summary.

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The problems of coal accumulation during different epochs in the geological history of the earth were brilliantly analyzed for the first by the late academician P. I. Stepanov in his well-known work which he presented in a paper before the Seventeenth Session of the International Geological Congress in 1937. Later he published a series of works elucidating these questions in more detail.

Stepanov presented the history of coal accumulation from the Devonian to the present from quite a new point of view. Data on geological reserves of coal basins and global deposits allowed him to establish the periodic character of coal accumulation with intermittent maxima and minima in the burial of vegetal matter that results in accumulation of coal. The Carboniferous-Permian period was considered the first maximum (the rate of accumulation ranging up to 54. 5 billion tons per million years), the Jurassic period as the second (about 60-65 billion tons), and the Tertiary as the third (about 76. 2 billion tons of coal). Thus, based on global coal reserves accumulated during geological periods, the Tertiary became the first maximum, the Carboniferous and Permian the second, and the Jurassic the third.

The Triassic and Cretaceous periods were considered periods of reduction in the processes of coal accumulation. However, Stepanov had indicated the possibility of discovering new large coal basins of Cretaceous age in the eastern part of Asia. As will be seen, this assumption has now been confirmed. Another assumption about the occurrence of major centers of coal accumulation in the north of Asia and in Alaska has also been confirmed.

During the last ten to fifteen years Soviet geologists in the eastern part of the U. S. S. R. have accomplished a great deal of work and have obtained new, extremely important information on Cretaceous coal accumulation. During study of problems of Cretaceous stratigraphy and of coal in Cretaceous deposits in the eastern Soviet Union, we have discovered coal in great quantity in Lower Cretaceous and Upper Cretaceous deposits of many regions, as well as an enormous region of Cretaceous coal basins. The same conditions exist in Alaska, which is adjacent to the far east of the U. S. S. R. Specifically, in its northern part American geologists, while prospecting

[1]Translated from "Melovoe ugleobrazovaniye i ego rol v protsessakh uglenakopleniya na zemle". Sovetskaya Geologiya, 1960, no. 2, p. 83-86. The paper was prepared by the author for the Twenty-first International Geological Congress and recommended for publication by the National Committee of Geologists of the Soviet Union. Translation reviewed for technical contents by Irving A. Breger.

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for oil north of Brooks Range, discovered large coal-bearing deposits. According to the earlier reports of P. S. Smith, T. B. Mertie, Jr., and others, major coal deposits only of Jurassic age were known to exist here. New studies have demonstrated that the greatest amount of coal and the greatest number of coal deposits are definitely associated with the Cretaceous. It is necessary to consider these coal deposits as a very large Cretaceous Alaskan coal-bearing basin covering an area of more than 50,000 square kilometers and having high coal-bearing series in separate regions. The coal deposits of Corwin, Kukpowruk, Kokolik, Utukok, Kuk, Meade, Ikpikpuk, Colville, Umiat, etc., are included in this basin.

During the Second All-Union Conference on coal in 1955 at Leningrad, having at our disposal data on Cretaceous coal accumulation in northeastern Asia and in northwest America as well as taking into account the possible Cretaceous age of the coal-bearing series of the Pacific coastal regions of North America west of the 100° meridian, attention was drawn to the fact that the Cretaceous period cannot be considered a period of reduction in the processes of coal accumulation, but that it must be considered a period of maximum coal accumulation.

The latest recalculation of data for coal reserves of the U. S. S. R., published in 1957 by N. V. Shabarov and A. V. Tyzhnov, confirmed the importance of Cretaceous coal accumulation. Almost 30 percent of the coal resources in the U. S. S. R. are associated with Cretaceous deposits. The largest basin in the world happens to be the Lower Cretaceous Lena basin, with reserves of 2,056 billion tons. Apparently this figure does not represent all the reserves of the basin.

Other major Cretaceous basins with coal-bearing areas and deposits are Ust'-Yenisseysky, with reserves of 222 billion tons; Zyryanka, 103 billion tons; Anadyr, 57 billion tons; Taimyr, 28 billion tons; Bureya, 25 billion tons, and others. The total reserve of Cretaceous coal in the U. S. S. R. is about 2,511 billion tons; this exceeds the total reserve of coal of all ages in the U. S. S. R. calculated at the time of the Seventeenth Session of the International Congress.

The latest data still do not represent the total reserves of Cretaceous coal on earth. Evidently, under the waters of the Bering Sea and Chukotka Sea (north of Alaska), as well as within the boundaries of the Sea of Japan (southern margins of Primorye[4] Lower Cretaceous coal basin and the northern margins of the Ryōseki basin in Japan), and finally in the lower reaches of the Kolyma, and possibly Indigirka, rivers, in the basin of Bolshoy and Malyy Anyuy, are concentrated the still undiscovered and little-studied coal basins and deposits that contain great masses of Cretaceous coal. If the reserves of Cretaceous coal in Alaska, and in North America in general, are taken into account, then their total reserves on earth will be close to the reserves of Tertiary coal and will exceed the coal reserves of the Permian age.

The growth of accumulation of coal resources during the geological epochs is shown in the following table, summazing data published in papers presented at the Seventeenth Session of the International Geological Congress, along with new recalculations of reserves in the U. S. S. R.:

System	Reserves in billion tons	Percent of the total reserves
Paleogene and Neogene	4,331	28.5
Cretaceous	2,627	19.5
Jurassic	2,109	14.0
Triassic	39	0.2
Permian	3,714	25.0
Carboniferous:		
Upper and Middle Divisions	1,944	12.0
Lower Division	202	0.1
Devonian	0.1	0.00

Data presented in this table indicate that beginning with the Devonian and during the entire Carboniferous period the process of coal accumulation was increasing and attained a maximum during the Permian age. During the Triassic period there was a recession in the processes of coal accumulation. This was followed by new, constantly increasing coal accumulation that continued up to the Cretaceous and Tertiary period. If the table were more accurate and allowed for the correlation of coal reserves of different rank, as well as for the introduction of corrections due to greater carbon content in Paleozoic coal, there would be no significant change in the ratio of coal reserves. If data on reserves of Cretaceous coal in Alaska and other regions were taken into account, the established ratio would undobtedly change in favor of Mesozoic coal accumulation.

The rate of peat accumulation during Quaternary time, as was mentioned by Stepanov, is unusually high. This evidently indicates that the process of burial of vegetal material which is converted into coal increases in magnitude with time.

The accumulation of coal does not depend on the scope of marine transgressions. The

[4] Far eastern maritime region in the Soviet Union (annotation of the translator).

Cretaceous period, as is known; was a period of enormous transgressions. As soon as the sea retreated, however, vegetation developed widely in the area which became available. Later, coal deposits, coal seams, and large coal basins were formed here. The Lena basin formed in such a manner in the territories that emerged after the retreat of the Jurassic Sea.

As is evident from the above, the belts and centers of coal accumulation formed on the land surface not only during Permian, Jurassic, and Tertiary times, but also during the Cretaceous period. The vast territory ranging from the northeastern and eastern margins of the Siberian platform through the basins of Alaska, the Kolyma and Anadyr rivers, and along the western coastal region of North America, may be considered as a Cretaceous belt of coal accumulation. As is known at the present time, within this belt are located the two largest centers of Cretaceous coal accumulation — the Lena and Alaska centers.

The diagram by Stepanov representing the manner in which the centers of coal accumulation were displaced in the course of time should be made more precise. The line representing the trend of displacement should be continued from the Permian coal basin of China in the direction of the Lena River (not in the direction of Japan), and further across the Kolyma and Anadyr rivers to Alaska and to the great Tertiary basins of North America.

The theory by Stepanov on belts and centers of coal accumulation was accepted by everybody a long time ago, and acquires more and more scientific value as the problems put on the agenda by Stepanov are solved.

The importance of this theory is supported by the fact of a regular change of accumulation sites where enormous amounts of vegetal matter were buried during definite periods of time, as well as by the fact of a constant increase, in the course of time, of the volume of vegetal matter on Earth.

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APPLICATION OF THE GEOBOTANICAL METHOD I HYDROGEOLOGIC STUDIES OF DESERTS AND SEMIARID REGIONS[1]

by

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• *translated by Gaida M. Hughes*[2] •

ABSTRACT

Plant associations in arid and semiarid regions serve as indicators not only of presence of ground water, but of its depth, relative salinity and seasonal variations. Plants such as phreatophytes may serve as direct water indicators, while Anabasis salsa, an indirect water indicator, is more indicative of geologic conditions, in this case clayey or argillaceous soils. An Anabasis salsa association n the Temirsk-Aktyubinska Ural region indicates that the ground water is located at considerable depth; in the northwestern Caspian area, however, this same association is often found in low wastelands forming localized impermeable horizons where ground water may be found at depths of 5 to 10 m. Some associations indicate the degree of salinity, rather than ground-water depth. Preparation of a ground-water resources map from such geobotanical data requires field work, during which associations around known wells, ponds or ground-water areas are analyzed to provide a criteria for the area as a whole. It has been found that data from field studies tally closely from that made from aerial photographs. Hence, after initial studies are made, prospecting of a given region may be carried out by aerial photographs. Variations in vegetation relative to depth and mineralization of ground water also may be used to forecast changes in the vegetation which would occur following construction of an irrigation system. --A. Eustus.

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THE VALUE OF GEOBOTANICAL OBSERVATIONS IN HYDROGEOLOGIC STUDIES

In the search for subterranean waters, for a number of years the geobotanists of the All-Union Aerogeologic Trust have utilized the geobotanical method. This method was of great help in the solution of hydrogeologic problems. The utilization of this method in prospecting for ground water at the present time has gained in importance due to the fact that it greatly reduces the time and cost involved in the construction of an irrigation system for arid regions of the southwestern U. S. S. R.

The purpose of this article is to present the experiences of the All-Union Aerogeologic Trust geobotanists who studied vegetation as an indicator of hydrogeologic conditions in desert and semiarid regions.

A group of phreatophytes, that is, plants whose root systems reach the ground water, may be distinguished among the vegetation of the deserts and semiarid regions of the U.S.S.R. This group serves as the most important geobotanical indicator of the presence of water. A contact of phreatophyte root systems with water, even with the margins of the capillary ground water, is an essential condition for their existence. Therefore, independently of atmospheric precipitation, plants of this group grow and develop very well during the entire vegetation period. Throughout their life span phreatophytes are so dependent upon ground water that the plant perishes when its root system becomes isolated from it. Because of the close relationship which exists between the vegetation and the depth at which the ground water is situated (especially under arid conditions), the plant cover and the plant associations may be used as indicators of ground water.

As a result of the studies made between 1948 and 1952 by the geobotanists of the All-Union Aerogeologic Trust, the most thoroughly studied plant associations — indicators — are those which indicate shallow (10 to 15 m down) ground water; this group then will be considered in this article.

Plant associations in which phreatophytes are the dominant species serve as direct water indicators because the distribution of these plant associations allows estimation of the depth at which ground water is situated, and often they also enable estimation of the mineral content of ground water.

Associations composed of other species but containing phreatophytes, may also be classified as direct water indicators. For example, a Stipa capillata-Festuca sulcata society with the presence of scattered individuals of the phreato-

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Translated from Primeneniye geobotanicheskogo metoda pri gidrogeologicheskikh issledovaniyakh v pustynyakh i polypustynyakh. Symposium: Geobotanicheskiye metody pri geologicheskikh issledovaniyakh: Tr. All-Union Aerogeologic Trusts, Ministerstva geologii i okhrany nedr, no. 1, Gosgeoltekhizdat, Moscow, 1955, pp. 44-60. Reviewed for technical content by Herbert E. Hawkes, Jr.

U.S. Geological Survey.

phyte grass Lasiagrostis was found in the Temirsk-Aktyubian Ural region. The dominant Stipa capillata and Festuca sulcata were not phreatophytes, but Lasiagrostis was one of the typical phreatophytes. This association was thus considered as a "direct" water indicator.

In addition to the direct water indicators, a large number of indirect ground-water indicators may be found among the plant associations. Dominant species of these associations are not phreatophytes and their root systems are not necessarily connected with ground water or with the capillary margins of the ground water. Very often, however, these associations are adapted to some lithologies which are characterized by definite hydrogeologic properties. Vegetation which serves as an indicator of these lithologies may at the same time be considered as an indirect indicator of the hydrogeologic conditions.

For example, plant associations which in the Temirsk-Aktyubinska Ural region serving as indicators of the Paleogene gypsiferous clays at the same time may be considered as indirect indicators of the fact that shallow ground water is absent. On the other hand, grasses growing over the upper Albian sands which contain fresh water serve as indicators of both the upper Albian sands and the fresh water. The presence of fresh water may be detected by the numerous springs as well as by the phreatophytes which grow at the points of contact of this sandy formation and the underlying clays.

The study of the location of one or another type of lithology by the plant cover also gives some idea as to the salinity of the ground water. G. I. Olovyanishnikov (1939, p. 107) writes that (in Central Fergan) "in clayey water-bearing beds the ground water and soils are more saline than in coarse-grained water-bearing beds".

Thus, plant associations which are not in a direct contact with ground water, but whose distribution reflects the lithologic-geochemical conditions and indirectly indicates the hydrogeologic conditions of a given area, are considered indirect hydro-indicators.

The chief difference between the direct and the indirect water indicators is that direct-indicator associations are always indicators of water, varying only in the details of their indicating value; i. e., under one set of geographic conditions a given association may serve as an indicator of more shallow ground water, while under another set of conditions it may indicate deeper ground water. The indirect water indicators found in one specific area, however, may not be water indicators in another area. For example, associations of Anabasis salsa develop principally on heavy soils (clay or heavy argillaceous soil) which contain sulfate salts. In the Temirsk-Aktyubinska Ural region they indicate argillaceous lower Albian or Aptian strata, and that the ground water under these plants is located at a considerable depth. In the Northwestern Caspian Sea area, however, Anabasis salsa often occupies low waste lands composed of clays which form localized impermeable horizons where ground water may be found at a depth from 5 to 10 m.

The distribution of direct and indirect water indicators in a given area gives some insight into the hydrogeologic conditions of that locality.

Vegetation on the slopes of elevations, gulches, etc., may also serve as a very sensitive indicator of the position of contact between impervious and water permeable horizons.

The detection of fresh water located close to the surface is a very important area where the geobotanical method may be utilized in hydrogeologic studies. Phreatophytes make it easy to locate small local accumulations of fresh ground water which may have the appearance of shallow water-bearing horizons of a lenticular form. In the desert this is especially characteristic for sandstone formations (Ramensky, 1951). In ordinary hydrogeologic mapping this water often goes unnoticed, even though in a desert it is the most accessible supply. Therefore, the determination of the role which the vegetation plays as an indicator of even shallow horizons and lenses of ground water, has a definite economic significance (Priklonsky, 1935, 1937; Antonenko and Pozdnyakov, 1942).

The areas most suitable for the location of a network of wells for the installation of irrigation systems may be found fairly quickly and cheaply through the plant cover.

TECHNIQUE IN THE STUDY OF WATER INDICATORS

Geobotanical studies for hydrogeologic purposes are called ground-water resource studies.

Such studies consist of two stages of work: 1) the determination of the value of vegetation as an indicator, i. e., the finding of direct and indirect water indicators in a given geographic area, and 2) the study of the distribution of these indicators and the preparation of the ground-water resource maps.

The technique for the study of phreatophytes and plant associations which indicate shallow ground water: i. e., the study of "direct" water indicators, is as follows. First, information on the phreatophytes growing in a given area is gathered from literature. The final determination of the value of a particular plant association as an indicator is done in the field. Careful geobotanical descriptions are compiled for areas which beforehand are known to contain ground water (close to wells, springs, drill holes and pits which have revealed water).

Geobotanical profiles are prepared for areas close to ponds and lakes, showing the changes in the plant cover which take place when the level of ground water changes. It is also necessary to make repeated observations of ground-water depth under the same plant association in different areas. In describing the vegetation, special attention should be given to the geomorphological conditions.

In describing the vegetation found around wells and ponds, first consideration should be given to the principal plant association which grows there rather than to mixed plant groupings which are frequently found under these conditions. In order to make a correct selection of the direct water indicators, it is necessary to study the root systems, the depth to which the roots penetrate, branching of the roots, and the contact of roots with ground water.

However, under field conditions these studies are rather difficult because they require at least semistationary observation. Observations of the phenological condition of plants are of a special significance. Under the conditions of arid regions, plants which have root systems in contact with ground water remain green during the whole summer, often blossom and bear fruit during the hottest periods of June and July. They are somewhat independent of precipitation.

A comparison of all the data collected (the observations should be repeated not fewer than 10 times for each association) provides information on the role of individual plant associations as water indicators. This, in turn, for a given region enables the preparation of the so-called ground-water resource outline.[3] Table 1 shows one of the many possible types of such outlines.

Different plant associations shown in the outline have a different indicating value. One group may indicate fresh or slightly saline ground water, while another one may serve as an indicator of saline or hypersaline ground water. Phreatophytes and associations where phreatophytes are dominant may be characteristic for a particular level of depth at which the ground water is located: a) the optimum

TABLE 1. Ground-water resources outline for one of the semiarid areas of the Ural region

Depth of ground water	Plant associations — indicators of ground water		
	Indicators of fresh, potable ground water	Indicators of slightly saline ground water, still potable	Indicators of nonpotable saline water
0-1.5m	1. Reeds in a complex of mesophytes 2. Association of willow and oleaster 3. Associations of reeds (growing on sand)	1. Reeds in a complex of saltworts (Salsola)	1. Sarsazan*
1.5-3m	1. Beach grass 2. Kyak* 3. Lasiagrostis — beach grass 4. Lasiagrostis — kyak* 5. Lasiagrostis — sophor*	1. Lasiagrostis — bidaek* 2. Lasiagrostis — Limonium	
3-5m	1. Lasiagrostis-Argopyrum** sibiricum 2. Societies of spreading Artemisia	1. Lasiagrostis — Alhagi pseudalhagi 2. Limonium 3. Associations of spreading Artemisia	
5-10m	1. Stipa capillata bushes 2. Stipa capillata-Festuca sulcata association with the presence of Lasiagrostis		

* Common or regional Russian plant names transliterated.
**May be Agropyron (wheatgrass family).

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[3] In actual field work only a preliminary outline is prepared. Later, when all information is collected from analyses of water, the outline is corrected.

depth of ground water where plants always reach their maximum development; b) the greatest depth of ground water, beyond which a given species disappears because of a lack of moisture; and c) the least shallow ground water where some species begin to suffer from excess moisture (Prinklonsky, 1937; Meinzner, 1927).

In this way it is possible to determine the most favorable depth of ground water level for direct water-indicator associations. Six groups of plant associations were found to be indicators of ground water located at various depths.

Group
I - down to 1.5 m
II - 1.5 to 3.0 m
III - 3 to 5 m
IV - 5 to 10 m
V - up to 20 m
VI - more than 20 m

Figures 1 and 2 present diagrams which were

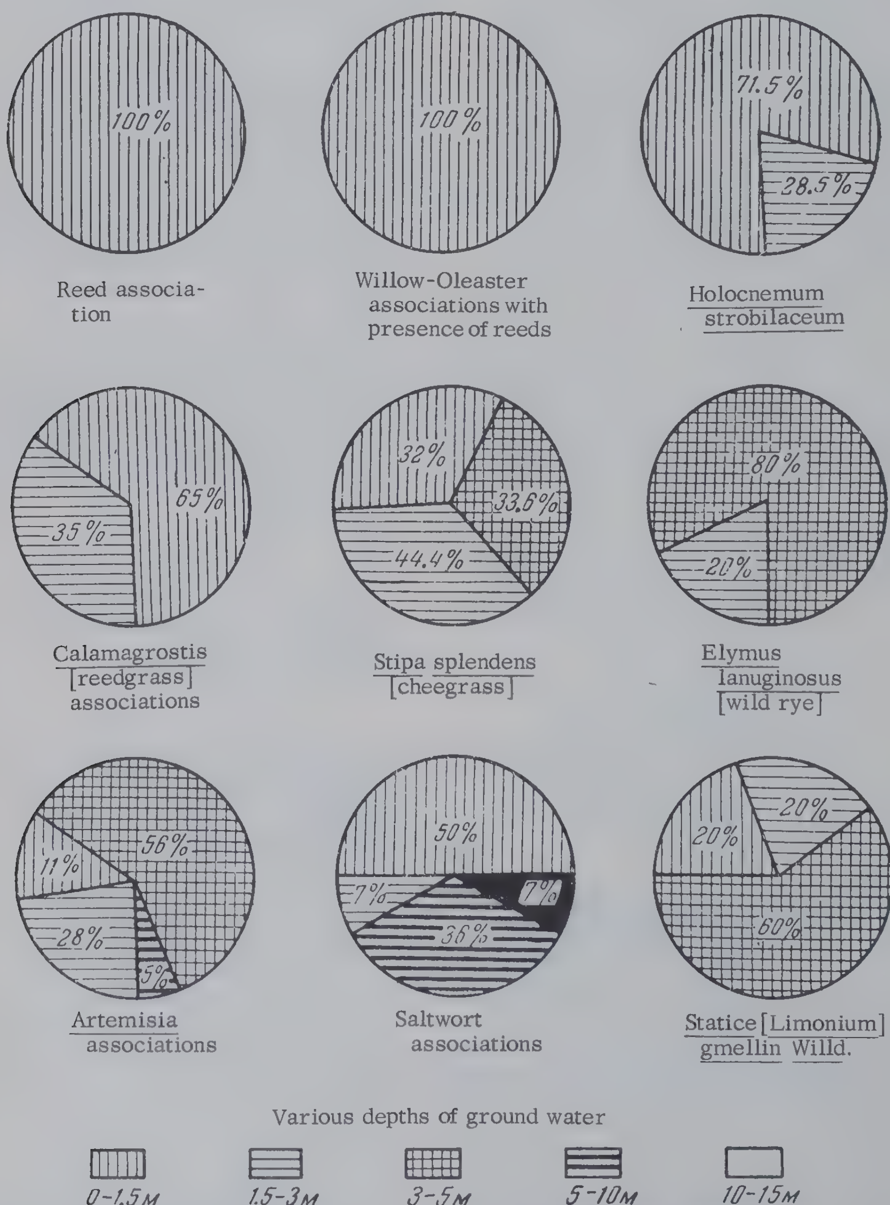


FIGURE 1. Ratios between the depth of ground water in various semidesert zone associations

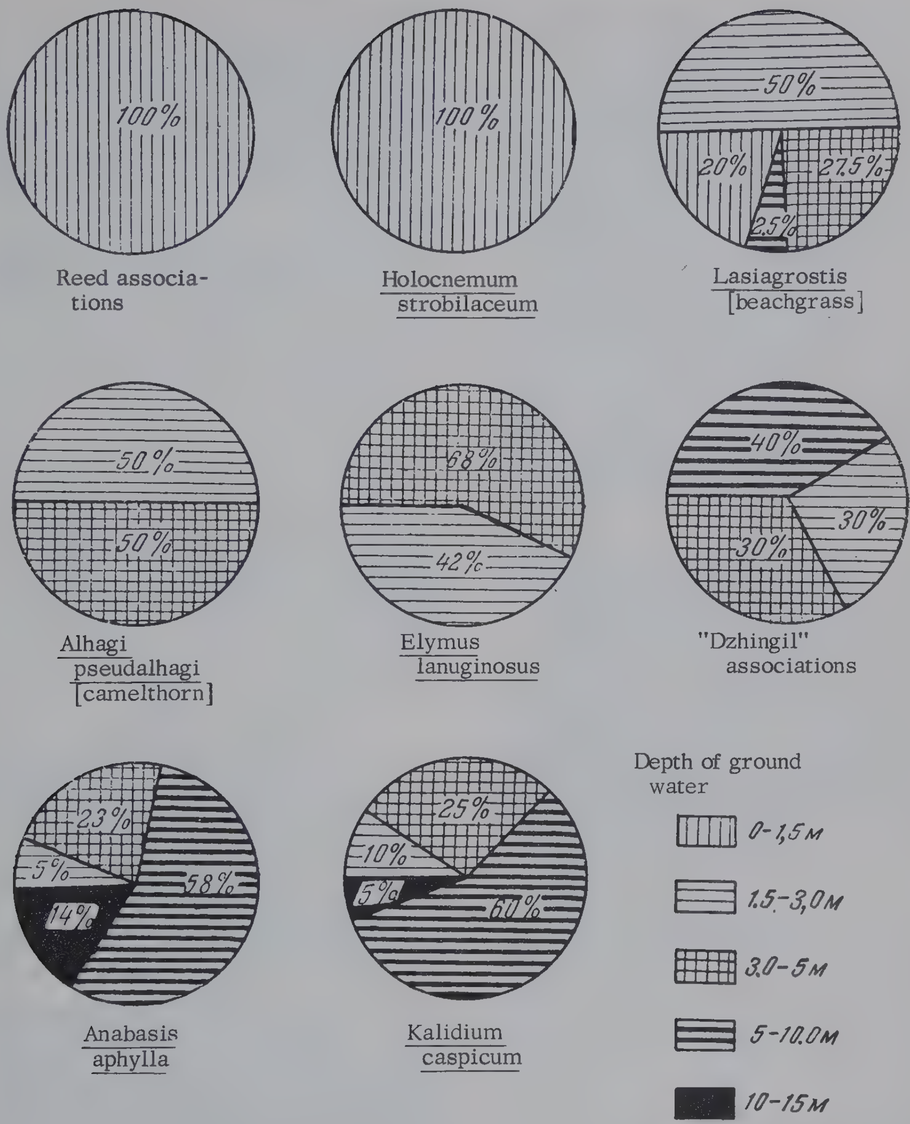


FIGURE 2. Ratios of the depth of ground water in various associations of the northern desert subzone

prepared as follows. The number of occurrences of ground water at different depths was computed for each plant association. Results of these computations were expressed as percentages. In this manner, the diagram indicates the degree to which a particular association is adapted to a specific depth of ground water.

The fact that for the same association a considerable range exists for the depth at which the water line is situated may be explained by the following fundamental principles:

1) the wider or narrower range of ecologic variation for the dominant phreatophyte or for the association as a whole;

2) seasonal variations in the level of ground water, which sometimes may be considerable;

3) plasticity of the plant root systems.

In studying plants as water indicators, these variations must be taken into account. Therefore, the ground-water resources outlines for each association should show the typical or characteristic range of the depth of ground water. For example, "potashnik" (a species of the genus Kalidum) associations in the northern deserts are found over various depths of the ground water (from 3 to 15 m), but they are mostly indicators of ground water located at a depth from 5 to 10 m down, since 85 percent of the "potashnik" associations were observed

within this depth range. Obviously, the most favorable ground-water depth range for this association is a depth from 5 to 10 m.

If the plant cover is used for a more exact prediction of the depth of the ground water, and of the extent of its mineralization, then it becomes necessary to make more detailed study of the entire association. The distribution of the dominant phreatophytes in such an association is most important. Distribution graphs are often used in such ground-water resource studies, contributing much to the knowledge of the role of plants as water indicators. For example, a comparison of distribution graphs for Stipa splendens in different associations showed that when fresh ground water was close to the surface (2 to 3 m down), the graph had a definite peak between 0 and 50 cm, but when the water was saline, the peak was higher (Vostokova, 1952).

A study of Anabasis aphylla from distribution graphs prepared for various depths of ground water in the Caspian Kara-Kum region leads one to believe that the density of Anabasis aphylla is more indicative of the depth than of the mineral content of ground water. In Fig. 3, curve 1 shows the distribution of Anabasis aphylla when ground water is to 5 m depth and has a variation in the mineral contents; curve 2 is for saline ground water, and curve 3 is for a moderately saline ground water. Curves 2 and 3 are almost identical, both being long and having low peaks. This would indicate a sparse distribution of Anabasis aphylla bushes. Curve 1 has a more definite peak and a sharp decline. Curve 4 shows the distribution of Anabasis aphylla when fresh ground water is located at a depth of 7.5 m. This curve has a definite, fairly high peak and an elongation which is typical for the distribution of this plant over deep-seated saline ground water.

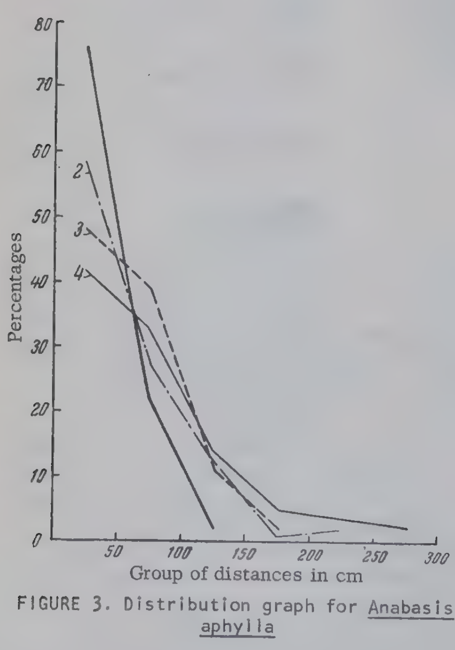


FIGURE 3. Distribution graph for Anabasis aphylla

1 - Region of the Tugobay-Kuduk well; 2 - region of the Tulekar well; 3 - region of the Tuzurp well; 4 - region of the Akurp well.

A comparison of the distribution graphs for Alhagi pseudalhagi (fig. 4) growing in different

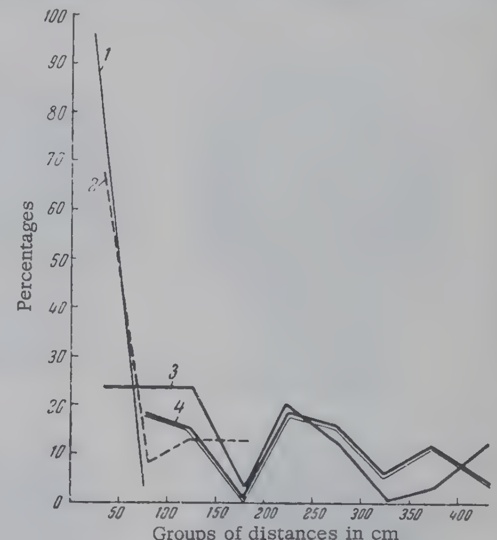


FIGURE 4. Distribution graph for Alhagi pseudalhagi

1 - Unbelmes springs region; 2 - Danata springs region; 3 - Kyz-Para well region; 4 - Yak-Yayla well region.

associations in Southwestern Turkmenia, showed that the salinity of the ground water was indicated not only by the appearance, but also by the distribution of the Alhagi pseudalhagi plants. More or less independently of the depth at which the ground water is located, the distribution of Alhagi pseudalhagi plants with regularity becomes more sparse the higher the salt content of the ground water. Table 2 illustrates this phenomenon.

The graphs prepared on the basis of this information may easily be divided into two groups: graphs 1 and 2 have very clearly expressed peaks and a sharp decline; graphs 3 and 4 have no peaks and are elongated. Graphs 1 and 2 show the distribution of Alhagi pseudalhagi over fresh water, graphs 3 and 4 show the distribution over saline ground water (fig. 4).

These examples show that in hydrogeologic forecasting, depending upon hydrogeologic conditions, it is possible to utilize such structural signs as the distribution of a phreatophyte in a particular association. This is most clearly

Table 2

Number of graph	The area studied	Depth of ground water in meters	Salt content in mg/liter	The number of measurements taken in percent in different distance groups									
				0-50	50-100	100-150	150-200	200-250	250-300	300-350	350-400	400-450	450-500
I	Ubelmes Spring	0	370	96	4	-	-	-	-	-	-	-	-
II	Danata Spring	0	830	68	8	12	12	-	-	-	-	-	-
III	Kyz-Para Well	1.7	5,223	24	24	4	20	12	0	4	12	-	-
IV	Yak-Yayla Well	2.0	7,671	18	14	2	20	16	6	12	4	4	4

illustrated by the distribution graphs. For one group of plants the distribution graphs may reveal mainly the depth at which the ground water is located, while for another group they may reveal the mineral content in the ground water.

Utilization of the distribution graph technique in prospecting for water is also of interest because in some instances it makes possible the utilization of aerial methods. For example, the distribution of large phreatophytes (such as bushes or small trees like Haloxylon aphyllum) may be studied from photographs. It has been found that the distribution graphs prepared from aerial photographs are identical to those which are prepared from measurements taken on the ground.

In searching for water, however, it is not sufficient to study only the domonant phreatophyte; a thorough study of the entire association must be made. A study of the accompanying, secondary species in a plant association is especially important in determining the degree and the type of salinity of the ground water. Thus, for example, such phreatophytes as Phragmites communis, Alhagi pseudalhagi, Stipa splendens, and some others, may be indicators of both fresh and saline water. This is clearly illustrated by Table 3.

Table 3

Names of species	Salt content in ground water in mg/liter	
	maximum	minimum
Phragmites communis	25,000	200
Alhagi pseudalhagi	12,000	700
Anabasis aphylla	15,000	400
Stipa splendens	10,000	200

For a more detailed forecasting of the extent of mineralization of water it is necessary to study the entire association, and especially its floristic composition. We attempted to determine the significance of different types of reeds, and it was learned that reeds, which generally are indicators of the presence of water, may be separated into different groups which by their floristic composition indicate different levels of mineralization of water. On the Kunya-Dar plain we separated different associations of Alhagi pseudalhagi and Karelinia caspica, the dominant phreatophytes. These associations were indicators of ground water located at a depth from 1 to 5 m, but chiefly 1.5 to 3 m. However, since there is a great possible range of variation in the mineral content of water, it is necessary to study in more detail the individual associations under the broad Alhagi pseudalhagi-Karelinia caspica association. These associations may be divided into two groups:

a) Alhagi pseudalhagi-Karelinia caspica associations which include halophytes,

b) Alhagi pseudalhagi-Karelinia caspica associations which include mesophytes.

The following halophytes are frequently encountered in the first group: Aeluropus litoralis, Statice [Limonium] otolepis, Zygophyllum oxyanum, and occasionally, Anabasis aphylla. Nitaria Schoeberi often is present when the soil contains up to 8 percent chlorides and up to 13 percent sulfate salts, but this plant develops best on light saline soils. This group of Alhagi pseudalhagi-Karelinia caspica associations also may include Kalidium caspicum, and less often, Halostachys caspica. In these instances, efflorescence of salt may almost always be observed on the soil. The salinity of water is high, with the quantity of chlorides reaching as high as 8,967 mg/L, sulfates as high as 4,337 mg/L and the dry residue being as high as 16,556 mg/L.

In the second group of Alhagi pseudalhagi-Karelinia caspica associations may be found Calamagrostis epigeios, Calamagrostis pseudophragmites, Setaria viridis, individuals of poplar, oleaster, tamarisk, and others, intermixed by Clematis orientalis and Cynanchum acutum. In areas covered by the associations of Alhagi pseudalhagi-Karelinia caspica and mesophytes, the ground water is either moderately saline or almost fresh. Thus, the chloride content varies from 148 to 223 mg per liter; sulfate content varies from 107 to 167 mg/L, solid residue is from 632 to 1,194 mg/L.

Thus, the hydrogeologic conditions of a given area may be forecast with greater accuracy when, along with distribution graphs, an analysis is made of the associations which serve as direct water indicators.

The very same phreatophytes and associations — direct water indicators — may be found over considerable distances, sometimes are located in different geographic zones or subzones. Although the fundamental indicational value remains the same, some variation is possible in details. For example, in the northern and southern desert subzones, tamarisk, Kalidium caspicum, Haloxylon aphyllum-Kalidium caspicum associations are the principal water indicators. For the entire territory of these subzones the indicational value of the above plant associations remains the same. But further to the north, these associations, as a rule, are found to develop in areas where the ground water is somewhat closer to the surface. Thus, in the southern desert, Haloxylon aphyllum with the presence of Kalidium caspicum is an indicator of ground water situated at a depth from 10 to 20 m, but the same association in the central Ustyurt solonchak basin (a northern desert) serves as an indicator of ground water situated at a depth from 5 to 10 m.

Kalidium caspicum associations in the southern desert are indicators of ground water at a depth from 5 to 15 m, in the northern desert they are indicators of water at a depth from 3 to 10 m.

A comparison of different plant associations serving as indicators in desert and semiarid regions, reveals that water indicating schemes which reflect the indicating value of each association must be prepared separately for each area (or subzone), because each area is characterized by its own specific associations — indicators of ground water. The indicating value of some associations in different subzones may also be different.

The close interrelationship of certain plants and plant associations with ground water suggests that a plant cover may indicate regular changes in the chemistry of ground water and of changes in ground-water depth. This is especially well-illustrated along the peripheries of inland drainage basins and small impounded bodies.

The distribution of plant associations indicating shallow ground water is of a great practical value because it provides preliminary orientation as to the hydrogeologic conditions. The changes which take place in the vegetation depending upon the changes in the depth and in the mineralization of ground water give an idea as to the changes in the vegetation which may be expected to occur from the construction of irrigation canals. Thus, there is obvious value in the study of the ecologic succession of plant associations around different ponds and inland drainage basins where the soil moisture conditions are already known. Vostokova (1953) studied some fairly typical ecologic successions around fresh water and saline basins, ponds and lakes in the western Kazakhstan, northern and northeastern Caspian areas, and partly, on the Priembensky plains.

PREPARATION OF GEOBOTANICAL GROUND-WATER RESOURCES MAPS

Preparation of geobotanical ground-water resources maps is the next step. Geobotanical ground-water resources map is a term used to describe a map which shows the distribution of plants and plant associations which serve as water indicators; i. e., maps, where the distribution of plant associations reveals the hydrogeologic conditions found in a certain area of a territory. Such maps are not strictly geobotanical maps because often they show inequivalent units of plant covering. For example, similar associations which are not water indicators may be combined into groups of formations and denoted by one index. On the other hand, associations with high water-indicating values (mostly direct water indicators) are always shown on the map, even though they may occupy very small areas of the total spread. In these instances, it is sometimes necessary to use values which are not included in the legend for marking the areas where especially important water-indicator associations are located.

In preparing a water resources map, the boundaries of large taxonomic units of vegetation (groups of associations, formation) are recorded so that they may provide a general picture of the plant cover and indirectly show also the hydrogeologic conditions. On this background then are marked the smaller units of vegetation, i. e., the direct water indicators which are of a special interest in hydrogeologic investigations.

Sometimes on the geobotanical ground-water resources map distinction must be made between individual species whose vitality and growth cycle differs from that of other species, since these differences may indicate a difference in moisture conditions (other conditions being the same). For example, according to the observations of S. V. Viktorov in southern Fergana (oral report), the presence of shallow ground water was easily detected by the prolonged flowering time (into late autumn) of the plant Perovskia scrophulariaefolia, while in the areas where ground water was not present, the flowering ended early and plants dried up. Sections with different development cycles of Perovskia were used by S. V. Viktorov as water indicators and were shown on the map.

The detection of water-bearing and water-impermeable horizons is important to the hydrogeologist. The bright, colorful areas of vegetation along the slopes of river valleys where all other vegetation is wilted indicates the presence of ground water (Lange, 1931, p. 163). This is because there is usually much

more moisture at the contact between water-bearing and water-impermeable horizons. Therefore, either associations adapted to shallow ground water develop in these areas or in contrast to the surround vegetation, plants have a longer growing period. Such areas would also be marked on the map; sometimes in the map legend.

The chief purpose of geobotanical ground-water resources maps is economic. Collective farms and state farms have been supplied not only from deep artesian wells, but also from ground water and shallow vadose wells. The geobotanical ground-water resources map, is a simple and descriptive aid in the selection of well sites. Such maps, which show by the plant cover the contact of different formations, the variation of rocks as to their water-bearing capacity, etc., are also of interest to the geologist and hydrogeologist.

Geobotanical maps also may be helpful in soil improvement projects. They show the areas where the ground water is located close to the surface and, in the event of irrigation, would rise above the critical level thus endangering the particular area with a secondary salinization. V. A. Priklonsky (1937, p. 17) writes that for hydrogeologic studies of irrigated areas "geobotanical information such as the character and distribution of the plant cover depending upon the depth and mineralization of ground water is of great interest".

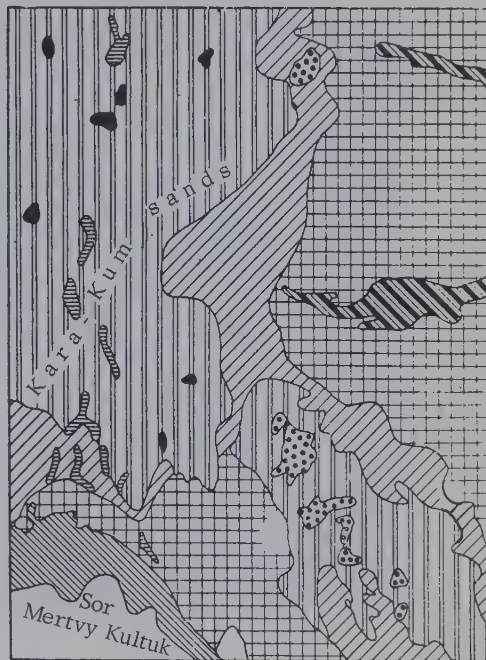
In desert areas, geobotanical maps for sandstone formations are helpful in the selection of sites for new wells and geobotanical data facilitate quick, inexpensive location of small water accumulations which are difficult to detect in ordinary hydrogeologic mapping.

Figure 5 illustrates a part of the water resources map for an area in the Caspian Kara-Kum region.

Aerial photography may greatly assist in the preparation of geobotanical ground-water resources maps. Associations indicating shallow ground water in a desert often are bright green in color, in sharp contrast with the rest of the vegetation, which turns yellow in early summer. Areas where the direct water indicators grow may be observed not only on the ground, but also from the air, and the dark green color is very clearly visible in aerial photographs.

Figure 6 shows how clearly an area with shallow ground water stands out on a background of dry solonchak, because the luxurious growth of vegetation appears on the photograph as numerous dark spots.

During recent years ground-water resource studies have become increasingly important in the deserts and semiarid regions on Kazakhstan and Turkmenia, where this method has already been fully justified. However, further studies and a perfection of the method are still necessary.



Sections most likely to contain water

- Alhagi pseudalhagi (ground water either fresh or moderately saline at a depth from 3-5 m);
- Anabasis aphylla (ground water either fresh or moderately saline at a depth to 8 m).

Others

- Artemisia-Agropyrum sibiricum association with the presence of Alhagi pseudalhagi in lower areas (ground water at a depth from 5 to 10 m);
- A complex of Artemisia and Artemisia-Agropyrum sibiricum society, Agropyrum sibiricum being present in lower areas (ground water from 8 to 12 m);
- Holocnemum strobilaceum (ground water bitter and salty at a depth to 1.5 m);
- A complex of Anabasis salsa and Halocnemum strobilaceum (ground water at a depth from 1.5 to 3 m and deeper);
- Groupings of Salsola (saltworts) (ground water salty bitter at a depth from 0 to 2 m);
- Anabasis on gypsiferous clays where ground water is located at great depths.

FIGURE 5. A geobotanical ground-water resources map

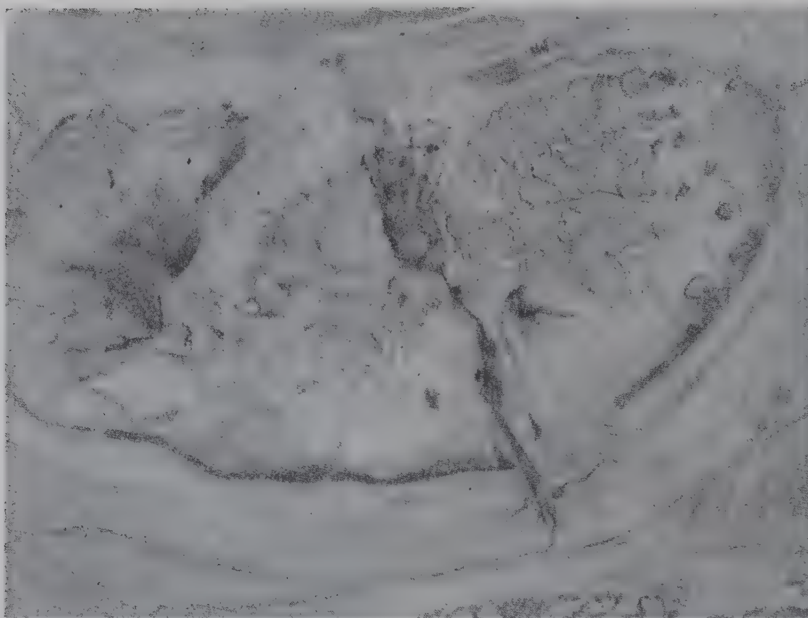


FIGURE 6. Hydrophytic associations in a solonchak valley

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AN EXPERIMENT ON THE UTILIZATION OF THE GEOBOTANICAL METHOD IN HYDROGEOLOGIC STUDIES OF THE CHERNYYE ZEMLI (BLACK EARTH) REGION[1]

by

L.S. Demidova, A.A. Shavyrina, Z.M. Kuzina, O.I. Fadeyeva and V.L. Levin

• *translated by Gaida M. Hughes*[2] •

ABSTRACT

The authors consider those geobotanical indicators which differentiate ground-water resources of varying salinity and depth. The territory under study is the Chernyye Zemli region; the aim is primarily to locate potable water for cattle. The most reliable fresh-water indicators were found to be certain sweet clover associations. The lower the mineral content of the water and the closer it is to the surface, the more luxuriant this plant species. A specie of sagebrush is another reliable sign. Moderately saline waters were marked by associations of wormwood with some dwarfed sagebrush and cypresses or with vetch, Gypsophila and wild rye. It is noted that the latter are indicators of moderately saline water when found in association with wormwood. Saline waters (dry residue over 12 g per L) were characterized by various sagebrushes, particularly Artemisia incana, and if this species is present in sweet clover associations even in small numbers, a higher degree of salinity is present. Field checking verified 78 percent of interpretations from aerial photography. --A. Eustus.

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The provision of potable water supply is one of the most important requirements for a complete and practical utilization of the Chernyye Zemli as a winter pasture for cattle from many regions and republics.

Great difficulties are encountered in this respect, because the water in the entire Chernyye Zemli territory comes from the highly mineralized Khvalnsky[3] water-bearing horizon and is virtually nonpotable. The pastures may be supplied with drinking water which comes mostly from local accumulations of fresh water (infiltration and condensation) found in the form of lenses principally in sandy formations.

Inasmuch as these fresh-water lenses are located comparatively close to the surface, it was found that certain plant associations composed of species adapted to fresh water, may serve as an effective indicator of the presence of fresh water. The results of studies of geobotanical prospecting for water in one section of Chernyye Zemli are presented below.

Ye. A. Vostokova's article, which also appears in this symposium, and which discusses the possibility of using vegetation as an indicator of the mineral content and the depth at which shallow ground water is located, has been taken as a theoretical basis for our investigation.

Our research was closely related to the research of hydrogeologists in the same territory. For the most part, geobotanical studies preceded the hydrogeologic studies, so that the information gathered by the geobotanists could be used by hydrogeologists in planning the locations for drill holes. Predictions made on the basis of geobotanical information were verified by drilling, and the cooperation of the hydrogeologists was very helpful to the geobotanists.

We used the conventional technique for water indicator studies. First, studies were made of the associations found on control sections near wells and bore holes known to contain water, to select suitable fresh-water indicators. Geobotanical and hydrogeologic studies of the Chernyye Zemli region showed that areas with fresh water accumulations were situated in the southwestern or western areas of wind-blown sand, where deflation basins were common. The depth of these basins ranges from 2 to 5 m and their bottom often is uneven. Buttes up to 3 m in height were scattered across some of the basins. The lowest parts of the basins usually are abutting directly to the aeolic sands. The basins are usually flanked on the North, South and East by sands, but sometimes a steppe covered with Agropyrum[4] desortum and Artemisia comes up to the basins. To delineate areas likely to contain water, all these landscape

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1 Translated from Metodika sostavleniya kart zasoleniya gruntov po geobotanicheskim dannym, Symposium: Geobotanichekiya metody pri geologicheskikh issledovaniyakh, Tr. Vsevsoyuznogo aerogeologicheskogo tresta [All-Union Aerogeologic Trust], Ministerstva geol. i okhrani nedr, no. 1, pp. 61-70, Gosgeoltekhizdat, 1955. Reviewed for technical content by Herbert E. Hawkes, Jr.

2 U.S. Geological Survey.

3 Khvalnskoye was an early name for the present Caspian Sea (G.H.).

4 May be Agropyron.

characteristics and geobotanical indications (to be discussed later) were taken into account.

Following are brief descriptions of the most common associations which serve as indicators of different types of water situated close to the surface.

ASSOCIATIONS — FRESH-WATER INDICATORS (Dry Residue from 0 to 3 g/L)[5]

The most reliable indicators of fresh water are associations where Melilotus polonicus is dominant; namely, the following associations: Melilotus polonicus, Melilotus polonicus — Elymus giganteus, Melilotus polonicus — Artemisia arenaria, Melilotus polonicus — Agriophyllum arenarium, Melilotus polonicus — Corispermum aralo-caspicum.

The roots of Melilotus polonicus grow to a length of 140 to 150 cm during its first season. During the second year they are 200 to 250 cm long and either reach the capillary water zone or are adjacent to the water.

The lower the mineral content and the closer the water is to the surface, the more luxuriant is the Melilotus polonicus plant. The vertical projection of this association (figure 1) shows the development of the Melilotus polonicus plants under such conditions. The range of depths at which the water is situated, and which may be determined by associations where the Melilotus polonicus is dominant, is not great. The least depth which we observed was 1.9 m, the greatest was 4.6 m.

Associations where Isatis sabulosa is present serve as another reliable indicator of fresh water. Isatis sabulosa is almost never dominant, but its presence even in small numbers indicates that the ground water is fresh. Most often Isatis sabulosa forms thin overgrowth on loose and wind-blown sands on the slopes and on the bottoms of deflation basins (fig. 2). The roots of Isatis sabulosa grow to a length of 5 m, but they do not always reach water, since the plant often grows on the slopes of the basins. Isatis sabulosa may be encountered in the following water-indicator associations: Elymus lanuginosus — Isatis sabulosa, Artemisia — Melilotus polonicus — Isatis sabulosa, and in the associations of Corispermum aralo-caspicum with the presence of Melilotus polonicus and Isatis sabulosa. These associations indicate that water is located at a depth from 3 to 4 meters.

In addition to the above-mentioned associations, the presence of fresh water may also be determined by the following associations: Artemisia (the variety which grows on sand), Artemisia — Elymus lanuginosus, Artemisia with the presence of Melilotus polonicus and

FIGURE 1. Vertical projection of Melilotus polonicus [Sweet clover], association

[5] According to the scale for Chernyye Zemli used by the Hydrogeologic Trust.

FIGURE 2. A photograph of Isatis sabulosa

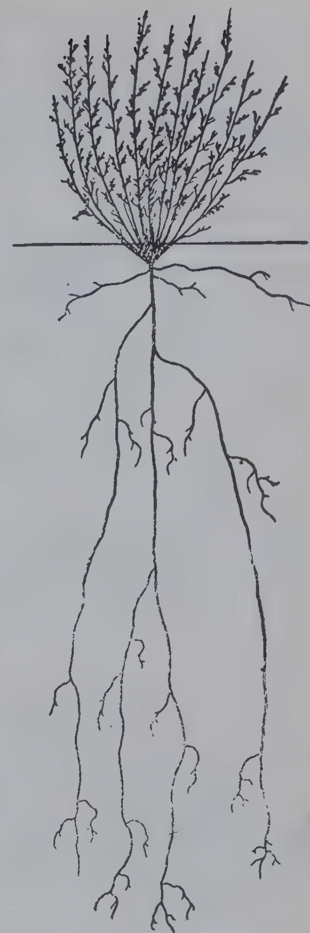

FIGURE 3. The root system of Artemisia arenaria

satis sabulosa, and the associations of Coris-
permum aralo-caspicum and Artemisia. Large
areas in the Chernyye Zemli region are cover-
ed by Artemisia. Most frequently it is found
on the edges of wind-blown sand massifs and
on loose sand. The roots of Artemisia grow to
a length from 3 to 5 meters (fig. 3).

The shoots, on the average, are from 70 to
90 cm long. Halophytic species in these as-
sociations are almost totally absent. Some un-
derstanding about the above-described associa-
tions is provided by the brief geobotanical in-
formation obtained from one section of a pros-
pecting pit which at the depth of 3 meters dis-
closed fresh water (dry residue 1.9 g/L).

	Abundance	Vitality
Artemisia arenaria	cop^2	5
satis sabulosa	rar	4
Corispermum aralo-caspicum	sol	4
Centaurea arenaria	sol	4
Melilotus polonicus	sol	3-4
Elymus giganteus	sol	4
Syrenia seliculosa	rar	4

Fresh water may be detected by Artemisia arenaria associations in those instances where this association surrounds the edges of solonchak depressions. The large perennial herb Elymus lanuginosus, which is very common on the Chernyye Zemli sands, may also be considered as a comparatively reliable sign of the presence of potable ground water. This plant has a well-developed root system which grows downward 2 to 3 meters and reaches the zone to which the capillary water ascends. Most frequently this plant grows luxuriously on soils that contain fresh or moderately saline water. Usually such soils consist of wind-blown sands. Only rarely does Elymus lanuginosus grow in areas where the saline ground water is situated close to the surface. The presence of saline ground water has a negative influence on the vitality of Elymus lanuginosus and changes the specie composition of the association by the presence of halophytes. Therefore, in attempts to determine the mineral content of water in areas where Elymus lanuginosus is the dominant

plant, it is necessary to take into account also the conditions of the habitat (the relief, the direction of the drainage of water, the cementation of sand, the structure of the association, the vitality of the Elymus lanuginosus plants, and the character of other plants in the associations).

The most reliable indicators of fresh water are the following associations where Elymus lanuginosus is dominant: Elymus lanuginosus — Isatis sabulosa, Elymus lanuginosus — Melilotus polonicus, and Elymus lanuginosis — Artemisia arenaria. Most often these associations are found in loose or almost loose sand in the deflation basins 3 to 4 meters deep. Elymus lanuginosus usually surrounds large wind-blown buttes at the bottom of the basins, and Melilotus polonicus and Isatis sabulosa patches grow luxuriously between the buttes. As a rule, toward the peripheries of the basin, there are fewer Melilotus polonicus plants, but more of Isatis sabulosa. Frequently the Elymus lanuginosus and Isatis sabulosa associations occupy the slopes of the basin and spread over to the rather loose sandy hills situated around the basin.

Analyses of water samples, taken from boreholes placed in areas where these associations are found, showed that the freshest water (dry residue less than 1 gram per liter) may be found under Elymus giganteus — Isatis sabulosa associations, and that the water with the highest mineral content (dry residue up to 2.9 grams/L) are found under Elymus giganteus and Artemisia arenaria associations.

ASSOCIATIONS — INDICATORS OF MODERATELY SALINE WATER
(Dry Residue 3 to 12 g/L)

The most common indicators of moderately saline waters are various associations in which Alhagi pseudalhagi is either dominant or abundant. Among such associations the following are most common:

a) association of Alhagi pseudalhagi with Artemisia arenaria and some halophtic, small scraggly bushes of Artemisia incana and Kochia prostrata;

b) association of Alhagi pseudalhagi with species typical for loose sands — milk-vetch [or locoweed], Gypsophila, and Elymus lanuginosus may also grow in this association. When found together with Alhagi pseudalhagi, these species are also indicators of moderately saline waters.

In order to predict the mineral content of water under Alhagi pseudalhagi, it is necessary to take into account the landscape factors. For example, when these associations grow in basins adjacent to wind-blown sands which serve as a source of condensation of fresh water, then the water under Alhagi pseudalhagi will be either fresh or moderately saline.

Some associations where Artemisia arenaria is dominant also serve as indicators of moderately saline water. Of these associations the most common are combinations of Artemisia arenaria with Artemisia incana and with Koeleria glauca, with Kochia prostrata, Artemisia salina, Agropyrum sibiricum. These associations are most often encountered on sand ridges or in shallow basins. It should be noted however, that here, as a rule, the salt content in water is higher beneath this association. The Artemisia arenaria — Koeleria glauca association is most often found in the northern part of this territory. Together with Artemisia arenaria, the following salt-tolerating species are most often observed: Kochia prostrata, Artemisia incana, Agropyrum sibiricum, and Artemisia salina.

SOCIETIES — INDICATORS OF SALINE WATER
(Dry Residue higher than 12 g/L)

In the Chernyye Zemli different associations where Artemisia incana is either dominant or present in great numbers, serve as the chief indicators of a very common type of saline ground water. To this class belong chiefly various Artemisia — Agropyrum associations which form the steppe that covers the major part of the Chernyye Zemli between sand massifs. The presence of Artemisia incana in other associations always means that the ground water has a high mineral content. Thus, if Artemisia incana appears even in small numbers in associations where the fresh water indicator plant Elymus lanuginosus is dominant, one may expect a somewhat increased mineral content and such water will be classified as moderately saline. Artemisia incana is one of the most important species to be considered when making geobotanical studies and predictions of the mineral content of ground water.

Saline waters may also be found by the following associations: Artemisia incana and Artemisia arenaria, A. incana and Alhagi pseudalhagi, Artemisia incana and halophytic species.

In addition to the Artemisia incana associations, very common salinity indicators are those where another salt-tolerating specie — Kochia prostrata — is dominant and may be growing together with Alhagi pseudalhagi and Artemisia arenaria. According to literary data (Fursayev, 1954; Larin, 1954), Kochia prostrata roots do not reach ground water and the distribution of this plant evidently is determined by the chemical composition of the soil.

Alhagi pseudalhagi together with typical saline soil species such as Limonium Gmelini and Aeluropus litoralis may also grow over

aline water, and occasionally it grows on soils here the mineral content of the brine is higher an 50 g/L.

Species of Tamarix, Limonium Gmelini and olocnemum strobilaceum associations are dapted to water with a higher mineral content. amarix plants are very common in Chernyye emli, and in areas where they grow the depth ground water ranges from 3.2 to 6.8 m, and e mineral content is from 18.2 to 47.3 g/L.

In addition to the above discussed very comon associations which are valuable in hydroeologic investigations, we also encountered a umber of less abundant plant associations which ay serve as indicators of the chemical comosition of ground water. Of these the Fourneortia sibirica with Elymus giganteus and asociations where Glycyrrhiza glabra is dominant erve as fresh-water indicators. Atriplex atarica and various species of the Suaeda genus ndicate saline water. Associations where ypsophila paniculata is present, and associaions where Stipa capillata is dominant, grow ver brackish water.

In order to predict the mineral content of he ground water, attention was focused not nly upon the floristic composition of associaions, but also on the vitality and density of the ost important species serving as indicators. hus, in attempt to determine the mineral conent of water in areas where Alhagi pseudalhagi rew, the foliage and density of Alhagi pseudlhagi was taken into account along with a whole eries of geobotanical and geomorphological igns. A number of observations were made or the purpose of determining the relationship hich exists between the foliage and density of lhagi pseudalhagi plants and the mineral conent of the ground water. As a result of these bservations, distribution curves and diagrams ere prepared, which showed the height and he diameter of Alhagi pseudalhagi plants growing over water with various mineral content.

A comparison of two curves and the diagrams for height and diameters, prepared from the mean values for fresh and moderately saline water (from 0 to 12 g/L), and from saline water (more than 12 g/L dry residue), produces the following results (fig. 4):

a) Alhagi pseudalhagi individuals over fresh and moderately saline water are taller than over saline water;

b) a greater density and regularity in the distribution is found over fresh and moderately saline water than on saline water. Over saline water Alhagi pseudalhagi forms a sparse and irregular cover with great distances between individual plants.

These differences in the distribution, height and diameter of Alhagi pseudalhagi are sharply expressed only in those instances where the differences in the mineral content of the water are greater than 3 to 4 g/L.

The following conclusions may be made in summing up the observations of the principal water indicator associations:

1. In the Chernyye Zemli plant cover a number of species have a tendency to grow over ground water with a definite mineral content. Over fresh water — Melilotus polonicus, Isatis sabulosa, Elymus giganteus, Syrenia seliculosa; over moderately brackish water — Alhagi pseudalhagi, Gypsophila paniculata; over saline water — Artemisia incana, Kochia prostrata, Artemisia salina, Limonium Gmelini, Holocnemum strobilaceum, Atriplex tatarica, and Tamarix.

2. A number of species occupy an intermediate position and grow in areas where the mineral content of ground water varies. Arte-

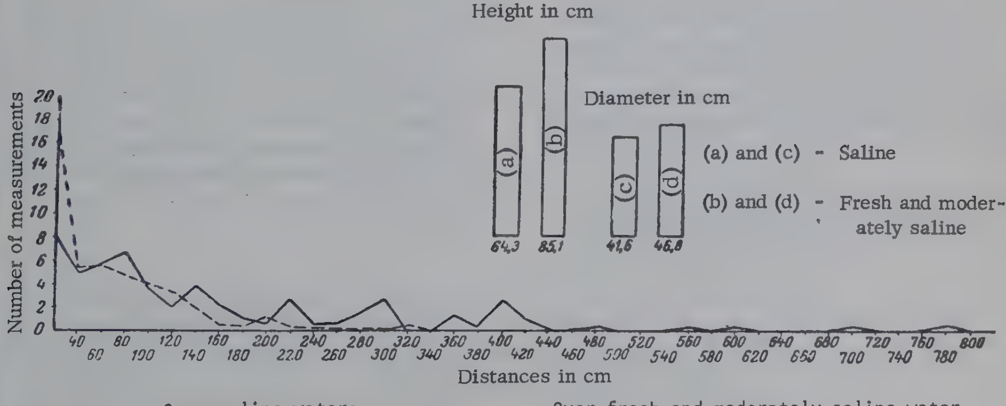

FIGURE 4. Distribution curves and a diagram of height and diameter for Alhagi pseudalhagi individuals depending upon the mineral content in shallow water

misia arenaria, which may grow over both, fresh and moderately saline water (but not over saline water), is a typical representative of this group. Alhagi pseudalhagi may also be considered as partly belonging to this group.

3. Many species, indicators of water, have a long root system which comes into a direct contact with ground water. A number of species which serve as indicators of the chemical composition of ground water, however, have a short root system which does not come into a direct contact with ground water. The connection of these species with ground water evidently is established in the following manner. A given species develops primarily on soils with a definite mineral content which affects the chemical composition of infiltration and condensation water accumulating in these soils.

ORGANIZATION OF GEOBOTANICAL INVESTIGATIONS FOR HYDROGEOLOGIC PURPOSES

It is necessary for the groups working on geobotany and hydrogeology to work closely together to obtain positive results from geobotany prospecting for water. The studies of Chernyye Zemli were set up in such a manner that the geobotanical parties carried out their studies on a somewhat smaller scale than the hydrogeologic prospecting parties.

As a rule, the work began with an aerial observation of the territory. This made possible the immediate location of sand massifs which were the chief accumulators of fresh water, and the notation of areas with abundant water-loving vegetation which by its dark green color stood out clearly against the background of sand.

The next step in the study was the preliminary interpretation and the setting up of a preliminary sampling grid.

Interpretation was done according to the complex of geomorphological and geobotanical signs. Especially great attention was devoted to the contouring of the wind-blown sands in deflation basins and to the contouring of the dark areas with succulent water-loving vegetation.

Then, a map of a scale determined in advance was prepared by means of an ordinary geobotanical mapping. The grid was made more dense in areas where fresh water plant indicator associations were located, but in areas where these associations were not represented, the preliminary grid became less dense. Ground-water source outlines on a larger scale were prepared for areas which were likely to contain water.

All the material obtained in geobotanical studies was turned over to the hydrogeologists to be used in the field. Thus, prior to the drilling in an area, the hydrogeologists received from the geobotanists a ground-water resources map of this area with notations of sections which contained geobotanical signs of fresh water, and ground-water resource outlines of these sections showing in detail the distribution of plant associations within a section. The points recommended for drilling usually were also marked on the material obtained in aerial photography.

Utilization of such a system of work was beneficial for hydrogeologic studies and also verified the accuracy of the predictions made by the geobotanist, confirming 78 percent of the hypotheses based on geobotanical data. In an area of 12, 580 km^2 geobotanists separated a total of approximately 120 sections which were likely to contain drinking water.

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COMPILATION OF SOIL SALINITY MAPS FROM GEOBOTANICAL DATA[1]

by

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• translated by Gaida M. Hughes[2] •

ABSTRACT

This paper covers not only the use of vegetation for compiling soil salinity maps, but indicates that soil salinity and vegetation anamolies may lead to discoveries of oil- and gas-bearing structures. In map compilation, the author stresses the need for correlating studies of various plant associations with borehole samples. The usual method was to take samples from the bottom of the borehole, from the root horizon and from overlying horizons. The importance of defining the type of soil salinity (sulfate, chloride or sulfate-chloride and also type of chloride) is emphasized. Examples are given where aerial observations of the vegetation led to further fruitful investigations. In closed basins, sulfate salts tend to be concentrated on the perimeter, chlorides at the bottom. Conditions contrary to this warrant investigation. In the Malyy Uzen region, for instance, growth of halophytes on an anticlinal structure, where drainage would be expected to create a low level of chloride salinite, led to the discovery of subsurface salt structures. On the Mangyshlak peninsula, an extensive system of faults was located by a chain of mounds of halophytic vegetation which followed one of the faults of the area. --A. Eustus.

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PROBLEMS AND BASIC METHODS OF COMPILATION OF SOIL SALINITY MAPS

The study of "halogenesis" processes, i. e., the processes related to mineralization and accumulation of salts, is of greatest theoretical and practical importance for geologic, hydrogeologic and geochemical studies of deserts and semiarid regions. In studying these processes often it is necessary to know the salt content in the soil, i. e., the salinity of the surface horizons of rocks which partly have been altered into soil and partly still represent subsoil bedrocks.

The dynamics of salinization is also of great interest. Such studies are of especially great value in the planning of various hydrotechnical and irrigation projects and in the reclamation of desert territories which may be irrigated and used for agriculture. In addition, a knowledge of the salinity of soil may be helpful in the selection of prospective oil-and-gas-bearing areas, since the work by V. A. Kovda, P. Slavin, and others (1952) showed that a relationship exists between the salinity of the surface horizons and the oil-gas deposits. Finally, due to the fact that some tectonic processes influence the character of salinity, a knowledge of the salt content in the soil may be helpful in the study of tectonic structure and processes (Dzens-Litovsky, 1951).

Utilization of the plant cover as an indicator, i. e., the geobotanical method, in the preparation of salinity maps, considerably facilitates the study of the salt content in the soil. Vegetation very sensitively reacts to any, even insignificant, changes in the salt composition, and therefore is a good indicator of salinity. A number of authors have mentioned the possibility that vegetation may be utilized in the characterization of salt content. Usually, however, the observations of the relationship between vegetation and soil salinity either were generalized, or else pertained only to some insignificant area. The geobotanical method for analyzing the salinity of a large territory was used for the first time in 1951 by geobotanical research groups of the Stalingrad Aerial Geologic Expedition of the All-Union Aerogeologic Trust, and since that time it has been applied to the Caspian Sea region around Ustyurt. This article is a brief generalization of methods used in the above studies.

From 1951 to 1954, the preparation of a salinity map by the author and a number of other geobotanists of the All-Union Aerogeologic Trust (T. V. Afanasyeva, S. I. Perlin, N. G. Nesvetaylova, G. I. Zhdanova, L. M. Starikova, V. I. Levin and others) was an integral part of complex aerogeologic studies and throughout this study a close cooperation was maintained with geologists. All work was oriented toward the single goal of preparing a soil salinity map which could be used by geologists, both as a source of geologic data needed for hydrotechni-

[1] Translated from Metodika sostavleniya kart zasoleniya gruntov po geobotanicheskim dannym, Symposium: Geobotanicheskiye metody pri geologicheskikh issledovaniyakh, Tr. VAT, Ministerstva geologii i okhrany nedr, Gosgeoltekhizdat, no. 1, 1955, pp. 71-81. Reviewed for technical content by Herbert E. Hawkes, Jr.

[2] U.S. Geological Survey.

cal construction projects and for the solution of problems pertaining to geochemistry and geotectonics (especially, problems of salt dome and oil-bearing structures).

In territories mapped, extensive geobotanical studies were carries out along with studies of the soil.

Investigations revealed that the application of the geobotanical methods increased the accuracy of work and reduced cost.

The geobotanical method of compiling salinity maps considerably reduced the amount of drilling and the number of chemical analyses required without decreasing the accuracy of the map, since drill holes were placed only for the purpose of establishing the relationship between the vegetation and the character of soil salinity. Thus, for example, the Academy of Sciences soil research groups in preparing a salinity map for the Caspian Sea lowlands with the scale of 1:200,000, placed twice as many drill holes as did the Stalingrad expedition. The boundaries between soils of different salinity were outlined on the basis of geobotanical information. This is especially important in using aerial methods (visual observation as well as aerial photography), since the peculiarities in the character of the vegetation are easily recognized on aerial photographs, while the different types of salinity (except those of solonchaks and solonetzes) cannot be distinguished on aerial photographs.

Besides, a soil salinity map prepared on the basis of geobotanical information obviously will be more accurate than a map which is prepared from even a very dense network of drill holes, since the samples taken from drill holes or trenches indicate the salinity only at these points; boundaries between the areas with different types of salinity located between these drill holes will always be somewhat arbitrary and subjective.

The salinity of the upper stratigraphic horizon may be determined when geobotanical information is utilized along with a limited number of analyses. Where the next stratigraphic horizon is located close to the surface (from 3 to 5 meters down), in some instances the salinity of this horizon may also be determined, since the roots of plants reach 2 to 3 meters and deeper (Shalyt, 1952, Petrov, 1933), and secondly, the nature of salinity of the underlying horizon has an effect upon the horizon situated immediately above it.

The mapping of soil salinity by geobotanical indicators usually consists of two kinds of field work: a) geobotanical mapping and b) the determination of the relationship between plant associations and the salinity.

For geobotanical mapping purposes, the entire territory is divided into a grid of aerial and on-the-ground mapping routes. Geobotanical identification of photographs and the preparation of a geobotanical map is done on this grid. Particular attention is paid to plant associations containing even a few of those plant species which react strongly to salinity. Therefore, the outlines on a geobotanical map may represent different taxonomic units from communities to groups of associations. If related plant associations contain species which indicate different types of salinity, then in mapping these associations must be broken down into the smallest taxonomic units possible. In some instances it is necessary to separate different plant associations on the basis of morphologic differences of the same species. Thus, for example, Anabasis aphylla L. associations having well-developed plants indicate a strong chloride-sulfate salinity, but associations with stunted Anabasis aphylla L. plants indicate a strong sulfate salinity. At the same time, when related associations differ by species which do not serve as indicators, or species with a similar indicational value, then only large taxonomic units will be used in mapping (groups of associations, etc.).

The relationship between the type of soil salinity and the plant cover is determined from the sample sections which are selected for each plant association. Characterization of these sample sections contains a detailed description of the vegetation (a general description of the area, computation of the absolute abundance, measurement of distances between individuals for the preparation of distribution graphs, the yield of harvest, etc.), and a description of trenches or drill holes placed down to reach the bedrock which is unchanged by the soil formation processes, and in some instances, even several meters down into bedrock. A sample of the bedrock is always taken to be chemically analyzed by either aqueous or hydrochloric acid extraction. In order to learn the dynamics of the salinity along the profile, it is desirable that samples also be taken from the overlying horizons. From each drill hole we usually took three samples: from the bottom of the drill hole, from the horizon in which the majority of roots terminated, and from the overlying horizons. It is also necessary to use the trenches dug by geologic research parties. In these instances, however, it should be remembered that the pits and trenches manually dug by geologists are typically placed only in locations of geologic importance. Therefore, it is unwise to depend solely on the geologists' borehole and drill work. Nor is utilization of outcrops, very old drill holes and wells recommended, since under the influence of outside factors the salt content here will have changed.

Experience showed that for a complete characterization of a geobotanical area including the

salinity of the soil, it is necessary to describe from two to five sample sections for each area.

In the attempt to determine the relationship between the vegetation and the salinity of the soil, the lithology must also be considered, since the salinity to a great extent depends upon the mechanical composition of the rocks and the composition has a considerable influence on the vegetation. Therefore, it is necessary in each sample section to obtain a detailed description of the deep drill hole or trench, and a mechanical analysis of samples from basic horizons. The mapping of the territory must be conducted in conjunction with the description of sample sections. This is done so that the geobotanical map will also reflect the character of the salts contained in the territory studied.

SOME CHARACTERISTICS IN THE DISTRIBUTION OF THE PLANT COVER DUE TO SALINITY

In the preparation of soil salinity maps a more homogeneous vegetation was noted on very saline soils or soils which contained chlorides that greatly affect the vegetation, than on soils which were less saline or contained the less harmful sulfates.[3] Thus, on the Mangyshlak peninsula and on the adjacent part of Ustyurt, both of the northern type of desert, out of a total of 35 geobotanical areas only one-third indicated the chloride type of soil salinity, although chlorides occupy more than one-half of the entire territory.

When the salinity maps were compared, and a single system of values established for the Northeastern Caspian Sea region, it was found that the same ratios for the adaptability of plant associations to soils with different salinity prevailed for much larger territories as well (from Fort Shevchenko on the Mangyshlak Peninsula to the Kalmykov village on the Ural river). On the average, for each type of low salinity there were 3 to 4 units of plant cover, but for each type of high salinity there were 2 (on Mangyshlak peninsula) to 3 (on a steppe in the Uralsk region) units of plant cover. A comparison of floristic listings revealed an especially high homogeneity in the plant cover on very saline soils. Thus, on the Mangyshlak peninsula, 29 species were found on saline and very saline soils which mostly contained chloride salts, but 66 species were distinguished on slightly saline soils, and those containing sulfate salts. It was noted that on very saline soils, many of the species were common to the Northern regions (steppes in the Ural region) and to the Southern regions (Mangyshlak); (25 percent of all the species observed on these soils were found in both regions). On slightly saline and nonsaline soils the similarity between the southern and northern regions was considerably less (only 12 percent of plant species were common). Thus, it becomes evident that the plant cover on very saline soils is rather homogeneous and that the same plant species will be found as indicators of a high degree of salinity both in the desert and in the steppe.

The cause of the comparative homogeneity of vegetation on very saline soils may be found in the fact that salinization is the principal factor in the environment to which the vegetation becomes adjusted. The influence of the remaining factors (lithologic composition of rocks, relief, climate) is of a lesser significance. On soils with a low salt content the vegetation is influenced by many ecologic factors which produce heterogeneity.

Frequently the saline soils are located at a considerable depth, while the upper horizons contain only insignificant quantities of salts. This was already pointed out by V. V. Dokuchayev (1891) for the Aralo-Caspian sediments. A similar position of saline and nonsaline horizons we observed on the Western Ustyurt and on the Tyub-Karagan peninsula (the Western end of the Mangyshlak peninsula), where they were composed of Neogene limestone and on the surface overlain by argillaceous-sandy eluvium. In this territory, in a number of samples taken at a depth from 0. 7 to 1 meter, the salt content was not higher than 0. 2 grams per 100 g of rocks, and only a greater depth did the salt content increase to 1-2 grams. In the limestone itself the salt content also was higher than 1 g per 100 g of rocks. Calcium sulfates were the dominant salts.[4]

This type of distribution of salts is reflected by the plant cover. The vegetation here is represented by Artemisia terrae-albae or by Artemisia terrae-albae — heteroherbaceous associations. Artemisia terrae-albae H. Krasch is the dominant specie. The grasses include Stipa capillata L., and Agropyrum[5] sibiricum (Willd.) P. B.

Those species develop on slightly saline horizons. At the same time, the plant cover includes a number of species which have a long root system and indicate a high degree of salinity of soil. Most often here may be encountered Anabasis aphylla, Kochia prostrata (L.) Schrad, and saltworts, of which the most abundant is the Salsola tamariscana Pall.

On some sand massifs of the Buzash peninsula (Igizlak, Zhilimshik) which contain as

[3] In the regions investigated, the low toxicity of sulfates was due to the fact that here they were mostly calcium sulfates often buried at a considerable depth.

[4] Carbonates, which comprise the principal mass of limestone, due to their poor solubility in water, were not found in aqueous extraction analyses.

[5] May be Agropyron.

much as 1 g of water-soluble salts per 100 g of rocks at a depth from 1 to 1.5 m, and less than 0.5 g per 100 g of rocks in the upper horizons, such salt-tolerating species as Kochia prostrata, Salsola rigida Pall., Anabasis salsa C. A. Mey Benth may be found among the Artemisia terrae-albae — heteroherbaceous psammophytes, which develop on less saline soils. In this manner the saline horizon located at some depth may be detected by individual salt-tolerating plants growing among glycophytic associations (plants which do not thrive on saline soils). Fedorov (1930) suggested that by vegetation it might be possible to determine the degree of salinity of different horizons.

An important conclusion regarding methodology is drawn from the above-mentioned examples. In the description of the plant cover, and especially in the preparation of a listing of plants, very great care must be taken to include even rare and scarce species, because their inclusion will insure the most complete predictions regarding salinity.

Considerably more complex is the detection of horizons with a low salinity when they are situated beneath horizons with a high salinity. This may occur in the event of a strong ascendence of salts as well as in the event when saline rocks from a higher terrain are deposited upon less saline ground. We observed such instances on the Mangyshlak peninsula west of the Sary-Tash landing where the Khvalinsky deposits were overlain by a very saline Cretaceous rock diluvium brought down from the Ak-Tau mountains. A similar phenomenon was also observed by Kovda (1937) for the Ustyurt slopes in the Kaydak salt lake region. In such instances the salinity of the upper horizons greatly affects the vegetation, which is principally represented by halophytic species. Thus, the following plants grow in the above-mentioned area: Atriplex canum C. A. Mey, Holocnemum strobilaceum (Pall) M. B., bushy Statice [Limonium] suffruticosa and Aeluropus Litoralis. The lower salinity of the underlying horizons was indicated by the fact that among the halophytic associations were found rare, isolated spots of plants which thrive poorly on saline soils.

The influence of horizons with different salinity on the plant cover in the Western Trans-Caucasus plains was described in the work of I. P. Veydeman (1953). She showed that in those instances where saline uppermost horizons were situated over less saline soil, the plant cover included Alhagi pseudalhagi or Lagonychium farctum which thrived on solutions obtained at some distance below the surface, and Petrosimonia branchiata and the perennial Aeluropus repens, which thrived on the highly mineralized soil solutions found at the surface.

In summing up the brief discussion of this question, it is necessary to note that vertical changes in salinity may be detected only through a detailed analysis of the ecology of species comprising the plant cover, and that this requires a careful and detailed description of the vegetation and a complete listing of plants.

ESTIMATION OF SALINITY UNDER A COMPLEX PLANT COVER

In those instances where the plant cover is complex, the estimation of the salinity of soil becomes a difficult task. A formation is composed of fragments of different plant associations which cover isolated small areas. Usually these fragments are composed of species ecologically very different from each other, i. e., they differ as to their relationship to the conditions of the environment. Vegetation complexes are most common in the semiarid zone where they include the components of steppe vegetation adapted to depressions (herbaceous and Artemisia terrae-albae-herbaceous associations), and the components of a desert vegetation which occupy the more level or elevated areas or miniature depressions (associations of Artemisia pauciflora and Anabasis salsa).

The complexes may contain 2, 3, or more members. The genesis of the complex may be different, but most often it is connected with micro-relief. In some instances the complexes may reflect even the geologic structure of the area. Thus, for example, on the Mangyshlak peninsula unique complexes were found in those areas where there was interstratification of sands and dark gypsiferous clays of the Albian stage. The Eurotia ceratoides — herbaceous association, adapted to sand beds, formed the general background, while narrow, irregular lines of Anabasis salsa and Nanophyton erinaceum, adapted to the outcrops of clay, were situated in depressions between the beds. This area is easily distinguished on aerial photographs. The Eurotia ceratoides — herbaceous associations on photographs appear gray, but the Anabasis salsa — Nanophyton erinaceum associations produce a darker color. For this reason the lines on the photograph are clearly marked, and are oriented in one direction, namely, from west-northwest to east-southeast.

In estimating the salinity of an area where the vegetation is of a complex nature, it is necessary to take as the principal indicator the size of the area occupied by individual components of the complex. If one of the components occupies a large area and the others form only insignificant spots on the general background, then the salinity found under the larger area will be used to characterize the entire section studied. In those instances where two or more components are found in approximately the same ratios, the soil will be said to have a mixed salinity, and it will be necessary to indicate the adaptability of plants to individual

types of salinity, to the elements of micro- and meso-relief and to the lithology. When the complexity in the plant cover is produced by differences in the geologic structure (as in the Mangyshlak peninsula case we examined), then it is necessary to consider the possibility of a mixed salinity of soils.

VEGETATION AS AN INDICATOR OF THE DYNAMICS OF SALINIZATION

By the plant cover it is possible to learn the dynamics of the salinization process and, what is especially important in the construction of irrigation projects, to learn the areas which are threatened by secondary salinization.

The appearance of salt-tolerating species among glycophytic associations in these areas will serve as a sign of ascending salts, even though the ascendance might be very insignificant. Very indicative in this respect is the appearance of succulent Salsola crassa, Salsola foliosa, Holocnemum strobilaceum M. B., and Obione verrucifera. Such areas are frequently encountered along the peripheries of estuaries in innudated areas.

By the changes in vegetation it is possible to trace the migration of salts, especially the migration of the easily soluble salts, from the top to the bottom of the watershed. As an example we will consider the vegetation on the Tyub-Karagan peninsula. An Artemisia terrae-albae and an Artemisia terrae-albae — "tyrs" association adapted to the carbonate-sulfate salts is located on top of the plateau. Anabasis salsa and Nanophyton erinaceum, due to the high chloride content in these areas, is present in the plant cover on the slopes. Finally, along the bottoms of the valleys grow Anabasis salsa and Holocnemum strobilaceum plant associations which indicate a high, and a very high sulfate-chloride salinity. At the same time in the center of the valleys stretch small ravines along which grow grasses and Artemisia, which would indicate that salts are gradually carried out of the valleys.

Literature specifies that in desert and semiarid zones the closed depressions have a concentrically distributed salinity, and that chlorides accumulate principally in the center of the depression, while the predominance of sulfates is observed along the peripheries. This is reflected in the plant cover and is one of the reasons why concentric bands of plant complexes have been described in many geobotanical publications. Such complexes have been observed by this author on the Ustyurt plateau north of the Uala natural boundry, where the growth of Holocnemum strobilaceum in the depressions marked the accumulation of chlorides, and Anabasis aphylla L. — Artemisia terrae-albae associations indicated a zone with a carbonate-sulfate type of salinity.

INTERPRETATION OF SALINITY MAPS IN GEOLOGIC STUDIES

Information on the salinity of soils facilitates the solution of some problems in geologic studies, especially of those problems which pertain to the geologic structure and to prospecting for mineral resources.

In the Caspian Sea region, the salt-dome structure areas revealed a high salinity even in those instances where the general character of the site suggests that a leaching should have occurred. One of the salt dome structures situated in the Malyy Uzen region may serve as an example. The shore of Malyy Uzen has been drained by a row of ravines and gulches, which prevent the accumulation of salts. Nevertheless, here we encountered a solonchak with Holocnemum strobilaceum, Salicornia herbacea L., and other saltworts. The solonchak was surrounded by Atriplex cana, which is an indicator of a strong sulfate-chloride salinity. Such an anomalous salinity was due to the existence of the salt dome which on the surface had outcrops of very saline rocks. The second salt dome, situated in a territory covered with flood alluvium, was identified by an Atriplex cana association which produced a large area greatly contrasted with the surrounding dense couch grass on the flood meadows.

Thus, we see that around some salt domes are found large areas with a high salinity. A. I. Dzens-Litovsky (1951) writes that it is possible to detect from a distance of several kilometers the areas which have a high salinity due to salt-dome structures. The detection of high salinity zones, especially if they have an anomalous position, may provide valuable information concerning the positions of the salt-dome structures.

In those instances when the tectonic changes have produced fissures along which very saline deep-seated water ascends to the surface, anomalous salinity also results and greatly affects the vegetation.

On the Mangyshlak peninsula, in one of the valleys in which was an extensive system of faults, we could observe the areas of tectonic disturbances by the vegetation. Along the bottom of the valley was situated a chain of mounds, whose dome-like form could easily be detected on aerial photographs. These small mounds in their appearance resembled colorful flower beds; their crowns were occupied by bright green Phragmites communalis L. plants but along the edges grew bands of Salsola. This chain of mounds coincided with the line of one of the faults located in this area.

Finally, the study of salinity sometimes may be helpful in the determination of geologic structures. This occurs in those instances when the salinity of outcrops of a given structure is

different than the salinity of rocks surrounding it. We observed such a phenomenon on the northern slopes of the Ak-Tau mountains (Mangyshlak peninsula), where the limestone outcrops of Cretaceous age with sulfate salinity were surrounded by Paleogene marls with sulfate-chloride salinity. S. V. Viktorov and L. F. Voronkova (oral reports) also found that the salinity of soils in southern Ustyurt reflected the tectonic structure of the region, but here the anticline areas had a higher salt content and could be considered as sources of salinity in the midst of the comparatively nonsaline, level surfaces of the plateau. The material investigated permits the following brief conclusion to be made. The study of soil salinity helps to solve problems pertaining to the geochemistry of surface horizons, aids in determining the geologic structure of the region, facilitates determining hidden structures and tectonic disturbances and has practical value in planning various hydrotechnical projects and detecting areas likely to contain oil and gas.

Inasmuch as the vegetation reacts strongly to changes in the salt content of the soil, it may be used to determine the salinity of soils. Utilization of the plant cover in studying soil salinity makes possible the application of aerial methods, both aerial observation and aerial photography. Besides, the utilization of vegetation considerably reduces drilling and analytical work, thus greatly reducing the cost of investigations.

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PERSPECTIVES FOR THE UTILIZATION OF GEOBOTANICAL GUIDES IN THE DETECTION OF SALT-DOME STRUCTURES[1]

by

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• *translated by Gaida M. Hughes*[2] •

ABSTRACT

In a hot, dry climate the presence of salt-loving vegetation (halophytes) may serve as a supplementary indicator of the presence of a salt-dome structure. Deep-seated oily water apparently forces the highly saline waters to the surface, where vegetation indicators may take two forms: where drainage is poor, the halophytes will be found along the anticline itself, but where drainage is good, the salt-loving plants concentrate along the perimeter of the salt-dome structure, sometimes virtually outlining it. In addition, the presence of gigantic and deformed plants in the area may indicate a high bitumen content. However, the influence of the deep oily water on the salinity of overlying deposits, soil and ground water varies with geologic conditions, depth and chemical composition of the ground water, conditions for its ascendance and conditions determining soil formation. The authors caution against over-simplification, since not every halophytic association indicates a buried salt dome; the specie composition of the association and presence or absence of bitumen-indicating forms must also be considered. --A. Eustus.

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According to the data obtained from geochemical soil studies (Kovda and Slavin, 1951), in a hot and dry climate the soils situated over oil-bearing structures become very saline because the overlying strata become enriched with easily soluble salts which ascend with a flow of water from the deep-seated accumulations of oil water. Under desert conditions these authors recommend the use of the soil salinity index as a very reliable supplementary prospecting guides for the discovery of buried oil-bearing structures. In the opinion of V. A. Kovda, the formation of currently saline soils is closely related to the ascendence of salts from deep-seated salt deposits, from saliferous sedimentary rocks, and from thermal waters (Kovda, 1937).

Somewhat later, A. N. Sokolovsky (1941) also concluded that salt domes or brines buried at some depth are one of the principal sources for the salinization of the upper horizons of the earth's crust. This author writes that solonchak, solonetz and solod may be utilized as indicators in prospecting for salt-dome structures and often to those structures related to petroliferous deposits.

In a hot, dry climate where ground water is located close to the surface, the soluble salts ascend to the upper horizons of the soil with the ascending current of deep-seated oil water under pressure. Due to the rapid evaporation, the upper strata overlying the ground water become enriched with soluble salts. As a result, the soils situated over an oil-bearing structure become very saline. The character and the degree of soil salinity to a certain extent reflects the specific salinity of the ground water which, in turn, becoming enriched with soluble salts from the deep-seated oil water, in their chemical composition are similar to the water associated with the oil deposits. In such a manner the water from the oil deposits is directly linked to the water in solonchaks on the surface.

The dryness of the air and lack of drainage of the territory promote not only the retention, but also the accumulation of salts. As a result, the soils situated over salt domes greatly differ from the soils in the surrounding area in their higher salt content.

The close relationship of the plant cover to local growing conditions, and in arid zones primarily upon the salinity of the soil, suggests that geobotanical signs might be utilized for the detection of salt-dome structures.

The work of the All-Union Geobotanical Trust expedition proved that in a dry and hot climate the plant cover is the most accessible and simplest indicator of soil salinity and that it may be successfully used in the compiling of soil salinity maps.

The author of this article has attempted to determine by salinity maps the relationship between the plant cover and salt-dome structures.

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[1] Translated from Perspectivy ispolzovaniya geobotanicheskikh priznakov dlya obnaruzheniya solyanokupolnikh struktur, Symposium: Geobotanicheskiye metody pri geologicheskikh issledovaniyakh: Trudy vsesoyuznogo aerogeologicheskogo tresta [All-Union Aerogeologic Trust], Ministerstva geologii i okhrany nedr, Gosgeoltekhizdat, Moscow, 1955, no. 1, pp. 82-88. Reviewed for technical content by Herbert E. Hawkes, Jr.

[2] U.S. Geological Survey.

Studies were conducted in one of the Caspian Sea regions which contained many salt-dome structures. In the first stage of the investigation it appeared to be worthwhile to learn whether any relationship existed between the areas with a varying salt content and the locations of the salt-dome structures. For this purpose the salinity maps were compared with the tectonic outlines prepared by geologists. Comparison of a structural tectonic outline showing the distribution of salt-dome structures with a soil salinity map prepared from geobotanical information revealed that the regions with salt-dome structures coincided with the areas of maximum soil salinity (see figure 1). Furthermore, to the salt domes were adapted areas which in their plant cover contained hypertrophic, abnormally formed plants that acquired the anom-

- Sor* with a band of Holocnemum strobilaceum growing along the peripheries; soils with an extremely high chloride salinity (>5 percent);
- Associations of annual saltworts, frequently in Anabasis salsa C.A. Mey Benth and Holocnemum strobilaceum complexes, on soils with a very high sulfate-chloride salinity (2-5 percent).
- Sor with Anabasis salsa associations growing on the elevated land between sors; sor has an extremely high chloride content, the soils of the areas between sors have a high sulfate-chloride salinity (1-2 percent).
- A complex of Eurotia ceratoides-Agropyrum sibiricum-Artemisia associations on sandy loam mounds and annual saltwort associations on lower land; the soil mounds which are elevated from 0 to 2 meters are practically nonsaline (0.25 percent); soils in the lower sections have a very high sulfate-chloride salinity (2-5 percent).
- Solonchak meadows with a complex of Artemisia-Agropyrum sibiricum associations growing on sand mounds; soils on elevations are nonsaline (0.25 percent); soils in the depressions have a high sulfate-chloride salinity (1-2 percent).
- Eurotea ceratoides-Agropyrum sibiricum-Artemisia associations on practically nonsaline soils.
- Contours of salt-dome structures.
- Areas with a hypertrophic plant cover.
- Fracture lines.

FIGURE 1. Coincidence between the areas of salt-dome structures and areas of maximum salinity

*Local name for Solonchak

alies due to the bitumen migration from the oil deposits (Buyalov, 1953). The results of this comparison are presented in Figure 1.

Unfortunately, special geochemical studies were not conducted. However, the chemical analyses at our disposal of ground water taken from drill holes located both over and outside of salt-dome structures gave some indication of the geochemical properties of the soil which are characteristic of ground water over oil-bearing structures. According to the studies made by V. A. Kovda and P. S. Slavin, a buried oil-bearing structure is distinguished by ground water with a very high salt content. It contains from 1.5 to 3 times more salts than does ground water from surrounding territories; it has an extremely high chloride content, and the water chemistry is similar to that of deep-seated water accompanying oil deposits.

Chemical analyses reveal that the mineral content, chloride content, and calcium chloride content in the ground water located over salt dome-structures is considerably higher than the salinity of the general area.

Table 1, which represents data from 12 chemical analyses, shows that the mineral content of soil and ground water outside of the salt-dome elevations ranges from 70 to 110 grams per liter, while the mineral content of the ground water over salt-dome structures ranges from 120 to 260 g/L.

water located over salt-dome structures has the same geochemical indexes which are characteristic for the soil and ground water of oil-bearing structures.

The territory which we studied is affected by the drainage action of the Emba river and its numerous tributaries, and therefore a lower salt content may be observed on some of the salt-dome structures where the relief is uneven. Thus, the sandy massif located over the fracture line in the salt dome (see the central part of the map) is elevated by one meter or more above the adjoining territory and the deep waters, ascending along the disjunctive fractures, flow freely toward the peripheries of the structures and accumulate in the depressions which surround the sand massif in a semicircle. Therefore, the soils situated over the fracture line are practically nonsaline on the surface. In the depressions, however, the soils have a very high sulfate-chloride salinity. Furthermore, in the southern part of the central dome, as a result of a systematic carrying off of soluble salts by Emba river spring flood waters, the soils adjacent to the Emba river have a lower salinity than the soils located in other sections of the salt-dome structure.

Similar phenomena in part may also be observed in other salt-dome elevations. In the principal characteristics, however (figure 1), the salt-dome areas coincide with the areas of maximum salinity of soils.

TABLE 1. Soil and ground water salinity index over salt-dome structures and outside the limits of the salt-dome structures

Salt Index	Over salt-dome structures						Outside the limits of salt-dome structures					
Total salts in g/L	206.7	121.3	211.6	260.4	160.5	183.8	92.6	102.3	96.6	85.1	72.6	109.6
$Cl^{+}; SO_4^{2-}$	12.5	12.2	44.1	20.0	15.0	9.7	4.5	5.3	.6	5.0	4.7	7.0
$\frac{Cl^{-}-Na^{+}}{Mg^{2+}}$	0.7	0.7	1.1	0.7	1.0	0.7	0.2	0.5	0.5	0.3	0.4	0.5

Furthermore, an analysis of the available material also reveals a higher chloride index ($Cl^{-}:SO_4^{2-}$) over salt-dome structures.

Thus, the ground water of the territory outside the limits of the salt-dome structures has a chloride index of from 4 to 7, but over salt-dome structures the same index ranges from 10 to 44.

The index of calcium chloride $\frac{Cl^{-}-Na}{Mg^{2+}}$ content in the soil and ground water outside of the salt dome elevations is from 0.2 to 0.5. The same index for the soil and ground water over salt-dome structures ranges from 0.7 to 1.1.

The above indicates that the soil and ground

The sections with maximum salinity are identified by the plant cover which is composed of groupings of various saltworts: Salsola crassa, Salsola lanata, Salsola branchiata, Petrosimonia glaucescens, Petrosimonia oppositifolia, Halimocnemis Karelini, Halimocnemis sclerosperma, and others. Saltworts occupy large solonchak depressions which have either a porous, cracked surface, similar to a swollen solonchak, or a smooth, level surface of the "takyr" [forerunner of solonchak] type. Individual saltwort species in different combinations produce a variegated plant cover. Holocnemum strobilaceum, Anabasis salsa and Anabasis depressa play a considerable role in the formation of the plant cover and sometimes they are dominant. A characteristic peculiarity of solonchak depressions is the presence of many areas with a bare soil

surface where there are no plants at all, or only sparsely distributed individual bushes of annual saltworts. Here the soil has a very high sulfate-chloride salinity.

The section with the maximum salinity, situated in the northwestern part of the territory under study, is a complex of solonchaks which occupy about 50 percent of the total area, and small elevations between the solonchaks occupied by Anabasis depressa. Solonchaks, which on the edges are surrounded by a ring of Holocnemum strobilaceum, have an elongated form and are arranged in narrow uninterrupted chains stretching in the direction from west to east at a distance of 100 to 500 meters from each other. The areas between solonchaks, covered with an association of Anabasis salsa, rise from 2 to 5 meters above the lakes, and are either flat or in some instances wavy in appearance. An association of Artemisia terrae-albae on the more elevated sections of the relief takes an insignificant part in the formation of the plant cover. The solonchak groups have an extremely high chloride salinity, but the soils between the solonchaks have a high sulfate-chloride salinity.

The rest of the territory is composed of either practically nonsaline soils or of a complex which includes nonsaline soils with those of a high sulfate-chloride salinity.

The practically nonsaline soils and those where the soluble salts are buried at a depth of 2 m and more are identified by an Eurotia ceratoides-Agropyrum sibiricum-Artemisia incana and Artemisia terrae-albae association, these plants being the chief components of the plant cover. Kochia prostrata plays only an insignificant role.

In some areas are observed wind-blown sands which in the plant cover contains the following psammophytes: Eremosparton aphyllum, Elymus giganteus, Artemisia arenaria, Calligonum aphyllum.

The southwestern section of the territory has a complex of Eurotia ceratoides-Agropyrum sibiricum-Artemisia incana association on the elevations, but saltworts in the depressions. The soils of the hills are also practically nonsaline but the soils of the depressions have a very high sulfate-chloride salinity.

Finally, a solonchak meadow complex with an Artemisia-Agropyrum sibiricum association has practically nonsaline soils on sand mounds and soils with a high sulfate-chloride salinity in depressions.

Thus, the attached salinity map, prepared from geobotanical information, shows that the plant cover is a good indicator of the degree of soil salinity, and that large sections of saltwort associations, which identify the soils with maximum salinity, coincide with the salt-dome structure areas. Consequently, an indirect connection is established between the plant cover and the buried salt-dome structures.

The specific chemical composition of the deep oil water determines the chemical composition of the salinity of soils located over salt-dome structures. The properties of soils located over salt-dome structures promote the growth of those ecologic plant forms which are capable of existing under the conditions of extreme salinity.

In this manner the deep oily water which influences the type and degree of soil salinity, to a certain extent also determines the type of plant cover which grows over oil-bearing structures. Therefore, the plant cover, while not having a direct connection with the salt-dome structures, nevertheless reflects the high salinity of soils caused by the presence of buried salt-dome structures or the deep waters accompanying the oil deposits located at depths in the earth's crust.

This provides a basis for posing the question of utilizing the plant cover as an indirect indicator of the presence of buried salt-dome structures in the earth's crust.

From this point of view maps showing the salinity of soils, based upon geobotanical information acquire a great significance as a supplementary material to indicate the areas of salt-dome structures. In addition, the presence of sections with gigantic and deformed plants in the area of salt-dome structures may be used as an additional evidence of high bitumen content, i. e., an evidence of the connection between salt-dome structures and oil deposits.

However, the influence of the deep oily water on the salinity of the overlying deposits and on the soil and ground water varies with the following: geologic conditions, depth and chemical composition of the ground water, conditions for its ascendence to the surface, and the general physicogeographic conditions which determine the character of the soil formation.

It should be noted that we observed the adaptability of large sections of saltwort associations to the salt-dome structure areas when the salt core was buried comparatively close to the surface (500 to 800 m).

In studies which utilize geobotanical information for the purpose of learning the locations of salt-dome structures, it is necessary that all factors which point to the presence of oil in a given area be taken into consideration. On the other hand, this question should not be oversimplified and every halophytic association should not be considered as an indicator of buried salt-dome structures. It is necessary

to consider the specie composition of an association and the presence or absence of plant forms which indicate a high bitumen content, etc.

It is necessary that in each concrete case a careful analysis be made of the causes of salinization of a given area, and that physicogeographic, hydrogeologic, and a number of other conditions be taken into account. Conclusions must be substantiated with geochemical data and only then may an area be recommended to the geologists as possibly containing salt-dome structures. Special attention should be devoted to the drainage of the area, since under desert conditions on an undrained relief the areas of maximum salinity, which are identified by saltworts, will coincide with the anticline of the salt-dome structure and, under especially favorable combinations of factors, they will outline the boundaries of the salt-dome structure.

If the territory is drained, saltsort association will grow at the foot of the salt-dome elevations in the appearance of a ring encircling them, and thus will indicate an anomaly of salinity.

In view of the fact that geobotanical studies are simple, convenient, and inexpensive, a geobotanical interpretation of soil's geochemical indices for petroleum deposits deserves attention and should be recommended for all prospecting work.

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UTILIZATION OF GEOBOTANICAL INDICATORS IN THE DETECTION OF TECTONIC DISTURBANCES[1]

by

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• *translated by Gaida M. Hughes*[2] •

ABSTRACT

The authors describe the method for determining the influence of tectonic disturbances on vegetation and give examples of such influences which were discernible in aerial photographs. In the case of the Sultan-Sadzhar basin, faulting has released ground water which produces a profusion of hydrophytic growth. In southwestern Turkmenia, a vegetation belt had been turned into a "graveyard" by faulting which brought saline waters to the surface. The percentage of dead specimens decreased with the increase of distance from the fault line. Distinct rectilinear belts of solonchak-type vegetation were noted from the air in tectonically-disturbed regions of both the above-name regions. --A. Eustus

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The occurrence of tectonic disturbances leads to deep-seated geochemical changes, which over long periods of time transform the entire natural appearance of a given territory, including its plant cover.

Under the influence of tectonic processes changes are produced in the soil and in the plant cover either as a result of changes in the hydrogeologic conditions, the outcropping of bedrocks which previously did not enter into soil formation processes, the ascendence of various solutions and gases along fractures, or as a result of changes in the consistency and mechanical properties of rocks located directly in the disturbance zones. Not all these influences will be examined here; we will consider only the possibility of using the changes observed in the plant cover as one criteria for locating lines of tectonic disturbance.

Changes which the tectonic processes produce in the plant cover have been inadequately investigated. To date, this question has been examined in some detail only by V. B. Sochava (1950). However, Sochava concentrated his attention primarily upon the description of large scale tectonic processes occurring over large territories and accompanied by general changes in the physico-geographic conditions. He did not touch upon the question of the influence that individual tectonic disturbance lines have on the local vegetation, and did not examine the possibility of using geobotanical guides and aerial study methods in studying the structure of the region.

Some references to the fact that tectonic disturbances in a certain manner affect the plant cover are to be found in literature. For example, Yu. P. Lebedev (1949, p. 238) in describing combinations of plant cover and soils in the so-called "sor-mound complexes" (i. e., hilly solonchaks with Holocnemum strobilaceum, species of the genus Tamarix and other halophytes), writes that "the distribution of sor-mound-solonchak complexes coincides with the areas of currently manifested tectonic activity."

Cuyler (1931) writes that over Cretaceous deposits in Texas, plant associations in which the hydrophytic species Doubentonia longifolia is dominant are found on the lines of tectonic disturbances. These associations grow exclusively in the areas of tectonic disturbances and identify the disturbance lines. The above-mentioned information suggests that unique conditions exist in these habitats.

S. V. Viktorov (1949) described a grouping of hydrophytic plants which formed a band stretching along a dome-shaped fault zone in the Paleozoic deposits of Eastern Fergana (Chul-Ustun and Chul-Mairam mountains). This strip of bright green vegetation stood out against the monotonous desert and low hill landscape in eastern Fergana and made it possible to trace the direction of disturbances on the ground as well as from aerial photographs.

D. P. Rezvoy (1949) described an interesting case where geobotanical information was used in studying the structure of an area. In an examination of aerial photographs Rezvoy noticed clearly visible dark sections which crossed the lighter background of some dry river valleys and produced forms which in their appearance resembled "bridges"). These bridges turned out

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[1] Translated from Ispolzovaniye geobotanicheskikh priznakov dlya obnaruzheniya tektonicheskikh narushenii. Symposium: Geobotanicheskiye metody pri geologicheskikh issledovaniyakh [Geobotanical methods for geological research]: Trudy Vsesoyuznogo aerogeologicheskogo tresta [All-Union Aerogeological Trust], Ministry of Geology and Petroleum Exploration, Gosgeolizdat, Moscow, 1955, no. 1, pp. 89-98. Reviewed for technical content by Herbert E. Hawkes, Jr.

[2] U.S. Geological Survey.

to be overgrowths of hydrophytic plants which grew in those sections of the river bed where ground water pressure is created by the rapid formation of folds buried in the strata underlying the river bed. Such phenomena have also been described by K. V. Kurdyukov (1951).

These facts, although unfortunately still incomplete, lead one to suppose that observations of the plant cover in conjunction with visual observations from the air and studies of aerial photographs may provide the geologist with useful auxiliary material to be used in his studies of the structure.

A group of geobotanists from the All-Union Aerogeologic Trust on many occasions had the opportunity to verify of such positions. Inasmuch as this question has not yet been thoroughly investigated, a detailed examination of some facts established by our researchers are deemed to be of value.

In 1946, S. V. Viktorov visited the basin of the Sultan-Sandzhar lake, located near Amu-Darya Valley on the southern border of the Khorezm oasis. The Sultan-Sandzhar basin was a very convenient location to observe the effect of tectonic disturbances upon the plant cover because geologists previously had determined that the deposits which formed the basin were broken up by a whole system of fractures.

Even prior to the field study, during a preliminary examination of aerial photographs, one easily could see the distinct, more or less straight lines which indicated the fracture grid. These lines were discernible on aerial photographs only due to the fact that they could be a speckled area of rather large (1 to 2 m in diameter) dark dots which produced bead-like configurations.

A field study of the causes for the emergence of the above-described pattern showed that large bushes of Tamarix hispida grew in chains along the faults, along with some other species of the same genus, and a number of hydrophytic plants. A description of one such line, illustrated in Figure 1, follows.

This fault stretches directly along the eastern shore of the lake. In relief it appears as a very low (less than 1 meter) ridge, composed of porous mass of fine soil and particles of salt, accumulated near the bushes, which stretch out in a chain along this ridge. This strip is approximately 100 meters wide. Tamarix hispida is the dominant species. Tamarix hispida bushes grow on the central section of the ridge. Near them sometimes are found the accumulative mounds — "chukalaki". The dotted appearance of the aerial photograph is produced by these Tamarix hispida bushes. On top and along the slopes of the wave-shaped elevated ridge between bushes of Tamarix hispida, grows a thick

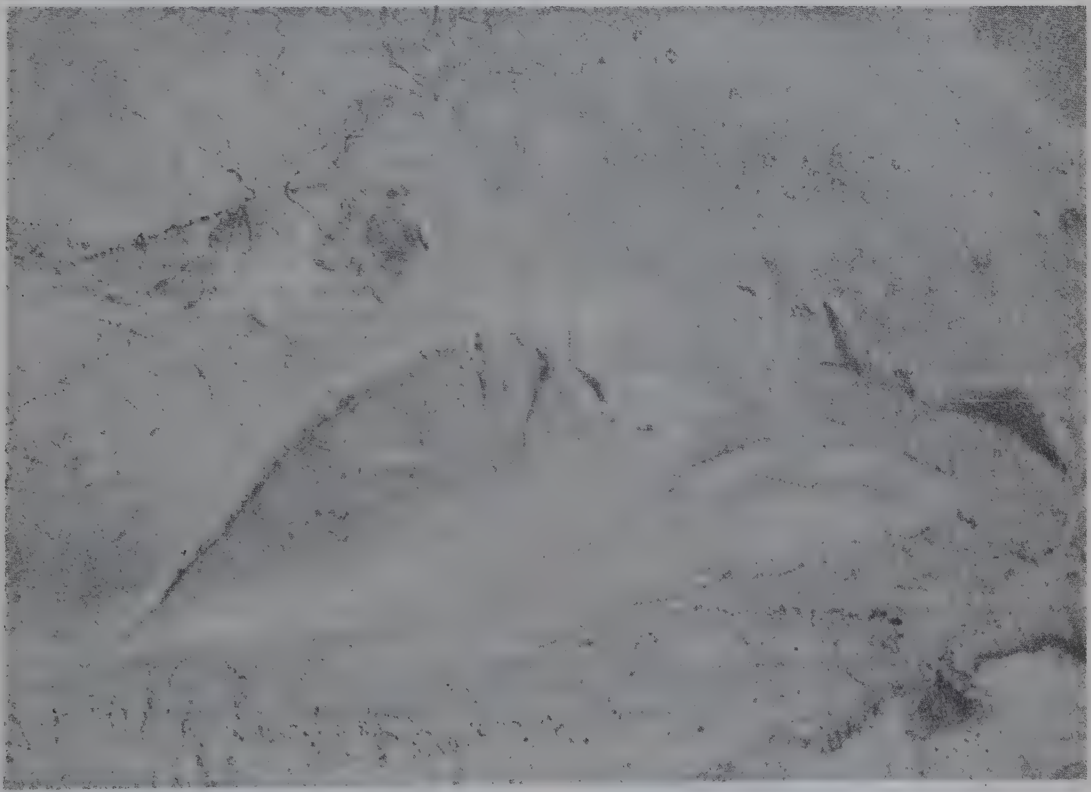

FIGURE 1. Line of faults indicated by a chain of small mounds

cover of the halophytic grass Aeluropus litoralis, while at the base of both sides of the slope are symmetrical overgrowths of large perennial saltworts — Holocnemum strobilaceum.

An examination of the aerial photograph reveals that the vegetation strip which stretches along the line of the fault contains large, dark sections which have contours similar to an isosceles triangle with the apex pointed toward the disturbance line. Such a section is especially distinct in the southern part of the photograph where the base of the triangle contour is surrounded by a unique fringe-like pattern produced by ravines and the vegetation growing in these ravines. Two similar, but less distinct sections are found on the northern part of the strip.

These sections are saltwort-reed swamps. The largest part of the swamp is covered by a reed overgrowth of the following composition:

Phragmites communalis — cop^3 — soc
Scirpus Cabernaemontahi — cop^3 — gr
Atropis sp. — sp. gr.

The edges of the swamp and the area of overflow where minute springs flow off the swamp, are covered with an overgrowth of halophytic plants: Silicornia herbacea and different species of the genus Suaeda.

Some, flat round mounds from 1 to 1.5 m in height are scattered on the strip. The mounds are crowned with reed overgrowths and water seeps out between groups of reed stems from the wet sand which forms these mounds. Slopes of the mounds have a dense Aeluropus litoralis cover, but a narrow chain of Holocnemum strobilaceum usually grows at the base. These mounds are clearly visible on aerial photographs; the two most noticeable mounds are located in the central portion of the line illustrated by Figure 1.

Thus, a whole complex of hydrophytic vegetation associations marks the tectonic disturbance line. These plant groupings differ greatly from the vegetation of the surrounding plains where the cover is composed of various combinations of Haloxylon aphyllum, Salsola rigida, some species of Artemisia and other drought-tolerating plants. It is this contrast which makes possible an accurate tracing of the disturbance lines on aerial photographs.

The attached aerial photograph (figure 1) also shows other disturbance lines which are marked by plant associations similar to those described. Especially clearly marked is a chain of large mounds — "chukalaki," situated along rupture disturbances in the extreme northeastern part of the photograph. The mounds are formed mostly around the Tamarix hispida bushes, but partly also around the bushes of solonchak plant Lycium turcomanicum. The bushy overgrowth completely covers the surface of the hills thus making them even more noticeable. Between the hills grow associations where the dominant plants are Aeluropus litoralis and Holocnemum strobilaceum.

In this case, evidently, the fault lines in the Sultan-Sandzhar basin are marked by the plant cover due to the existence of unique hydrogeologic conditions. The ground water obviously is located close to the surface at the disturbance lines, a fact confirmed by direct observation. Thus, the above-described swamps serve as areas where small springs emerge by seeping through the sticky, black mud cover of the swamp, and flow away along numerous shallow ravines. The proximity of ground water has caused the development of hydrophytic vegetation.

Another area where we studied the influence of tectonic changes upon the plant cover of some young structures was southwestern Turkmenia. These structures appear as elevations divided by a complex network of faults. An aerial photograph illustrates how clearly noticeable are the disturbances in this area (figure 2).

In the study of the plant cover of these elevations, the extremely stunted appearance of plants and the presence of large areas covered by dead plants of different species, mostly perennials, allowed a more exact identification of the vegetation bands which gravitate toward the fault lines. Here, dead specimens of Hololachne songorica, Salsola gemmascens, S. arbuscula, S. Richteri and Haloxyllon aphyllum plants and other trees and bushes covered enormous areas and produced an extremely depressing picture of a collosal graveyard of plants.

In a study of the distribution of dead specimens it was found that dying-off was most common along fault lines. This was most clearly revealed when the numbers of dead and living plants were computed per area unit (1 to 4 m square) directly on the fault lines. Sample areas numbered 25 usually, and sometimes as many as 200 (for studying a large fault, as in the aerial photograph, fig. 2). We selected parallel areas at various distances from the fault lines (25 to 100 m, or more) and computed survival percentages, i.e., the mean percentage of living plants of a given species to the total number of plants of the same species in a given series. A comparison of results showed that the survival percentage on the fault lines was zero, and that the percentage increased with the distance from the faults. This phenomenon is graphically illustrated in Figure 3. The distances from the tectonic disturbance lines are shown on the abscissa, and the percentages of survival are shown on the ordinate.

These observations showed that on the struc-

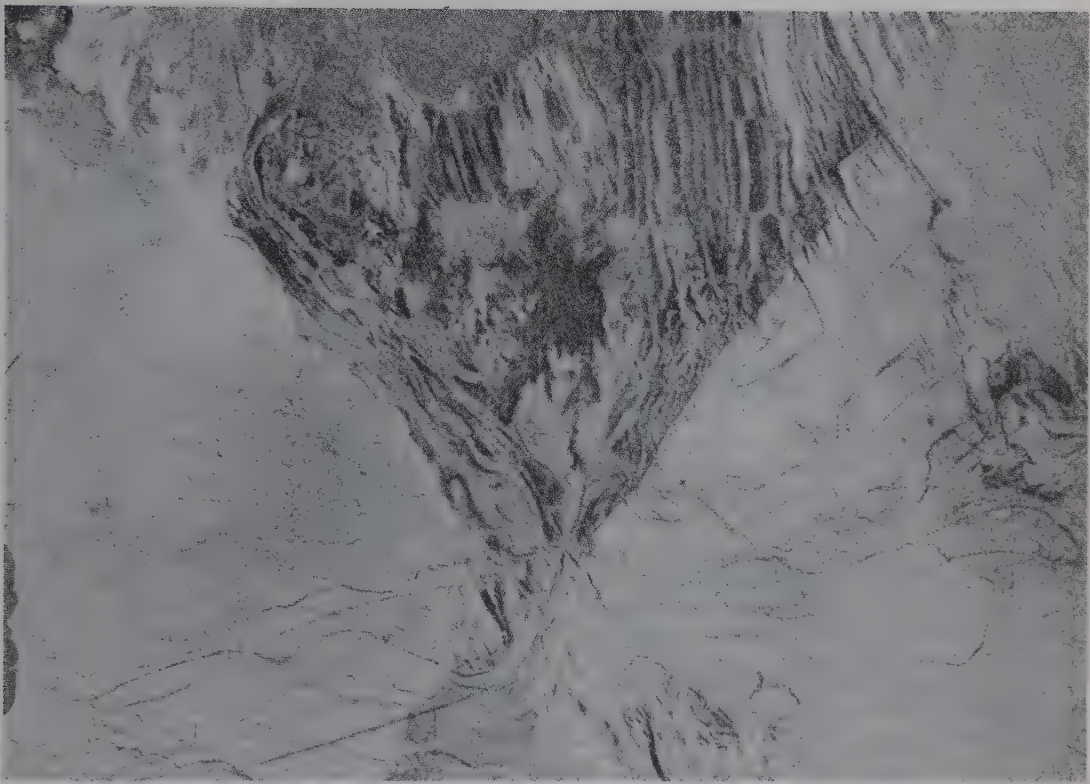

FIGURE 2. Large ruptured disturbance causing mass perishing of vegetation

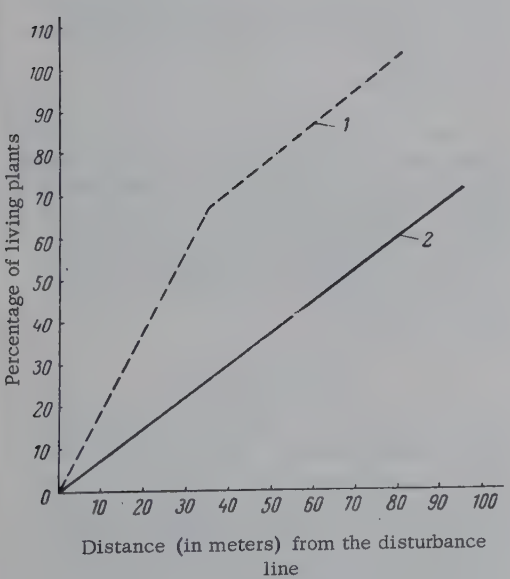

FIGURE 3. Graphic illustration of the survival of plants at various distances from the line of tectonic disturbances

1) - Calligonum junceum; 2) - Salsola Richteri (Russian Thistle).

tures investigated the influence of the lines of tectonic disturbance was responsible for the mass dying-off of the plant cover. A study of the geochemical processes appeared to be the best approach for learning the explanation of this phenomenon. The salinization process was the most distinct geochemical process observed on the described elevation. Chemical analyses of samples showed a considerable salinity of the fault zones. For example, in one of the drill holes placed directly on the fault line, at a depth of 100 cm, the total salt content (determined by aqueous extraction) was 9.1 percent, but 250 m away from the fault the total was only 1.0 percent. Such ratios were observed frequently. High salinity on faults evidently is produced by the ascendence of highly mineralized thermal subterranean waters which in some places produce hot fountains with a mineral content of 10,000 mg/L. It should be noted that the shores of springs originating at such fountains were covered with a crust of salts and had no vegetation of any kind.

The migration of salts to the surface evidently was an important cause (possibly not the only cause) for the stunted development, and in some areas, for dying-off of the plants.

The role of faults as paths along which the salts ascend, was especially clearly revealed

on the "takyr" regions which surrounded the elevations. Here, under a heavy alluvium stratum (as thick as 15 m) which was not affected by ruptured disturbances, the buried bedrock was broken up by a complex system of ruptures. The "takyr" sections where these buried structures were present, acquired a somewhat saline character, which resulted in corresponding changes in the composition of the plant cover.

This evolution process whereby the "takyr" is changed into a solonchak, evidently, was somewhat accelerated during the past years as a result of earthquakes in this region, which activated the already present disturbances. At any rate, in many territories it is possible to observe different transition stages of "takyr" into a solonchak, i. e., processes, which are opposite of those which are usually observed in southwestern Turkmenia.

According to the observations of G. M. Proscuryanova, the earliest stage of the salinization process produces mass perishing of the vegetation which is usually found on a "takyr" (Gololokhna dzhungarskaia, Haloxylon aphyllum and "tetyr"), and causes the springing up of various halophytic plants (Aeluropus litoralis, Holocnemum strobilaceum, species of Kalidium and others). The sections on which the "takyr" plants perish, often have the appearance of rectilinear strips. V. P. Miroshnichenko, of the aerial-study methods laboratory of the U. S. S. R. Academy of Sciences, showed similar strips which marked one of the largest regional disturbances in this region. The latest, clearly distinguishable stage of the "takyr" evolution into a solonchak, is the formation of Holocnemum strobilaceum-covered hills on which are dispersed individual mounds covered with Tamarix passerinoides bushes.

The "takyr" evolution into solonchaks is especially clearly apparent on sections which have a straight line configuration and stretch along the "takyr" in straight, wide bands. In many instances such lines are distinguishable on aerial photographs and appear as darker areas on the light background of the "takyr". Since it was possible to establish some correlation between these strips and the location of the structures which were known to exist in this region, the location and direction of the strips lead one to suppose that the development of these strips is in some manner dependent upon the buried faults. In a number of instances the solonchak strips on the "takyr" run between neighboring structures which emerge to the surface and form between these structures something resembling a "bridge" joining them into a single system.'

Thus, the study of the position of solonchak strips on the "takyr" enabled partly the tracing of some tectonic elements of the location, which could not be observed directly, and to determine the buried connections between different structures.

In individual instances, by the development of the solonchak areas it is possible to determine the boundaries of structures which are buried under a light alluvium stratum, or which emerge at the surface but are leveled by washouts (for example, in the Yalma-Kuidu natural boundary region).

In summing up the instances where the tectonic disturbance lines were determined by geobotanical information, it should be mentioned that according to the examples cited, the most important of these is the distribution of solonchak plant associations and the formation of unique rectilinear strips of solonchak vegetation. The development of such strips along the tectonic disturbance lines was noted in both regions investigated, — in the Sultan-Sandzhar basin and in Southwestern Turkmenia

Rectilinear boundaries and geometrically accurate contours are not characteristic for sections with normal plant associations. Therefore, the sharp delineation and the unique contours of the described solonchak strips of vegetation (as well as strips of hydrophytic plant associations, noted in the Sultan-Sandzhar basin) clearly stand out among the ordinarily irregular and poorly defined boundaries between plant associations. It is, therefore, recommended that in aerial geologic identification, careful consideration be given to the general picture of plant cover and that all elements of the plant cover which have a rectilinear outline be separated.

On these strips of interest is the appearance of unique phytogene accumulative formations of Holocnemum strobilaceum (i. e., overgrowths of large perennial solonchak plants — Holocnemum strobilaceum which are encircled by accumulated mounds of sand and sandy loam) and of small mounds, "chukalaks" — both of which often are found in regions with a high tectonic activity.

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CLASSIFICATION OF PYROCLASTIC FLOWS[1]

by

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• *translated by Reiko Fusejima* •

ABSTRACT

Pyroclastic flow is defined as the flow of high-temperature, essential, fragmental materials. This is synonymous with the nuée ardente in the broad sense. Three modes of emplacement of high-temperature, essential, solid (or liquid) materials after the ejection from the crater may be recognized: 1) Projection of fragments from the crater by explosive expansion of gas within the crater; 2) descent of fragments or liquid magma from the crater caused only by the action of gravity; and 3) swift downflow of the mixture of gas and fragments. This last is intermediate between the first two and corresponds to pyroclastic flow.

A new classification of pyroclastic flows is proposed based upon viscosity of the materials, which is inferred from the nature of the deposit. The volume of the deposit increases as the viscosity decreases.

1) Nuée ardente in the strict sense: Represented by the nuée ardente of Mt. Pelée, Merapi, etc. The fragments are less porous, which indicates the high viscosity. The volume of the deposit is small, generally less than 0.01 km^3.

2) Pyroclastic flow of the intermediate type: Represented by certain pyroclastic flows of Asama, Hakone, and Myoko volcanoes. Both viscosity and volume (0.1 - 1 km^3) are intermediate between 1) and 3).

3) Pumice flow: Represented by pumice and tuff flows of all sizes, such as those of Crater Lake, Hakone, Katmai, and Aso volcanoes. Low viscosity leads to full vesiculation into pumice. Many of them are larger in volume (> 10 km^3) than 1) and 2), and calderas of the Krakatau type are often formed after the eruption of larger pumice flows.--Auth. English summ.

* * *

INTRODUCTION

Ejection of high temperature materials in volcanic activity takes various form. As far as the essential materials (derivatives of a magma that are directly related to the volcanic activity) are concerned, the mechanism of transport from volcanic vents can be classified as follows:

1) Fragments of magma are blown into the air with a certain initial velocity, by the rapid expansion (explosion) of gases in the cratèr, and rain to the ground. To this category belongs the ejection of volcanic bombs and blocks in the Vulcanian or Strombolian type of eruptions.

2) Magma extruded from the crater comes downslope due to gravity. In this case, ejection of the magma is not explosive. When the viscosity is low, the magma flows down as a lava flow, but when the magma is more viscous it forms a dome (or spine) and later breaks into blocks that tumble downslope.

3) Fragments of magma continue to emit gases after ejection, so that the mixture of gases and magma fragments flows en mass downslope. This type of ejection is intermediate between, and grades into, types 1) and 2).

The genetic name "pyroclastic flow" is here given to flows of high-temperature essential materials caused by eruption type 3). The phenomena included in this term correspond to the nuée ardente in the broad sense. However, usage of the term nuée ardente has not been rigorous, and thus the term is confusing. Therefore the writer advocates the term pyroclastic flow that has been used previously by Gilbert (1938), Williams (1941), and others.

PYROCLASTIC FLOWS

Before the classification of pyroclastic flows is discussed, the nature of these phenomena will be summarized.

In May 1902, Mt. Pelée, an active volcano on Martinique Island in the Lesser Antilles, became active. Repeated small explosions were followed by the extrusion of almost solidified magma into the summit crater, forming a lava dome (which later became a spine). On May 8, a great explosion at the summit shot an enormous quantity of volcanic blocks and ash almost horizontally toward the south as if they were fired from a cannon. The ejecta formed a massive black cloud which, in only one minute (Lacroix, 1904), reached the town at St. Piérre

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[1]Translated from Bulletin of the Volcanological Society of Japan (Kazan), v. 1, no. 1, pp. 47-57, January 1957.

[2]Geological Institute, Faculty of Science, University of Tokyo.

8 kilometers from the mountain. This black cloud instantly devastated the town and killed about 30,000 people.

During several months that followed, more than ten similar explosions took place. This unusual calamity attracted much attention and a large number of survey reports were made, among which Lacroix's paper (1904) gives the most detailed account.

Lacroix pointed out that such an eruption seldom had been known throughout the world, and named this phenomenon nuée ardente (meaning incandescent black cloud). Glowing cloud, Glutwolke, and hot cloud [in Japanese] are translations of nuée ardente. Since then, nuée ardente generally has been accepted as a special type of volcanic eruption, and gradually similar examples have been recognized from other volcanoes. For example, Soufrière Volcano on St. Vincent Island, Lesser Antilles, commenced its activity at about the same time as Mt. Pelée and issued many nuées ardentes (Anderson and Flett, 1903; Lacroix, 1904). From 1929 to 1932 Mt. Pelée became active again and spouted thousands of nuées ardentes, though on a smaller scale than during the 1902 activity (Perret, 1937). Merapi Volcano of Java is reported to have issued nueés ardentes, damaging farms, men and cattle, fifteen times during the period from 1587 to 1943. The nuées ardentes of 1930 to 1931 were especially large (Neumann van Padang, 1932). Small-scale nuées ardentes were reported from Sakurajima Volcano in 1914 (Omori, 1916; Koto, 1916) and in 1939 (Tsuya and Minakami, 1940). On the last day of the great eruption of Asama Volcano of 1783, a large-scale nuée ardente (Kambara nuée ardente) formed during the explosion of the summit crater, resulted in a great deal of damage (Aramaki, 1956). Other volcanoes in Java, Mexico, the Philippines, and New Zealand are known to have erupted nuées ardentes.

As more examples of nuées ardentes have been witnessed, and the resultant damages and deposited materials investigated, the mechanism of nuée ardente movement has become a subject for discussion. Various views have been expressed on the subject, such as by Lacroix (1904), Fenner (1920, 1937), Perret (1937), Williams (1941, 1942), Macgregor (1952) and Verhoogen (1953). These views, with appropriate deletions, are summarized in the following paragraph.

The nuée ardente is an avalanche of almost consolidated essential blocks (fragments of highly viscous magma) mixed with high pressure, high temperature gases. This mixture, being violently agitated, rapidly flows en mass downslope. Gas is continuously emitted from the essential blocks, causing them to explode in succession and giving an appearance as if the whole flow was boiling. Because of the lubricating nature of the emitted gas, the nuée ardente appears to have remarkably low viscosity, despite its relatively high density. As a result, the mass becomes a powdery body, and travels very rapidly (in most cases nuées ardentes have a velocity of 10 to 100 m/sec) even on gentle slopes. Therefore, a prerequisite for the birth of a nuée ardente is the development of high gas pressure (probably one hundred to several hundred atmospheres) that results in the bursting of bubbles continuously emitted from the mass of rock fragments. Termination of vesiculation ends the life of a nuée ardente. The phenomenon of development and growth of vesiculation is seen even after fragments of magma are separated from the main body (after they were ejected out of the crater), as exemplified by the formation of bread-crust bombs. The mechanism of such delayed vesiculation must be exceedingly complex, being controlled by a variety of physical and chemical factors (Verhoogen, 1953). Empirically, nuées ardentes are limited to andesitic and dacitic magmas; no examples have been described from basaltic magmas. This may be a function of magma viscosity. We know that when the edge of a thick lava flow or lava dome collapses, a nuée ardente forms and flows downslope. We also know that an almost dying nuée ardente is reborn when it falls into a depression. From these facts it is evident that collision of rock fragments in nuées ardentes triggers vesiculation.

LARGE-SCALE PYROCLASTIC FLOWS

In addition to the may eyewitness accounts of nuée ardentes that have been reported, it has become acceptable to assume that some of the pyroclastic deposits, whose eruptions were not directly witnessed, may have been formed by the same mechanism as the nuée ardente of Mt. Pelée. Mt. Katmai of Alaska burst into eruption in June 1912. Fenner (1920), who surveyed the area several years after the eruption, pointed out that great quantities of pumiceous deposits filling the Valley of Ten Thousand Smokes west of the volcano were deposited by phenomena closely resembling the nuées ardentes of Mt. Pelée and Soufrière.

Subsequently, huge rhyolite tuff deposits attributed to a similar origin have been found in the Taupo-Rotorua district of New Zealand (Marshall, 1935), in eastern California (Bishop tuff; Gilbert, 1938) and in southern Peru (Cordillera tuff; Fenner, 1948).

Williams (1941, 1942) studied Crater Lake, Oregon, and many other calderas throughout the world. He deduced that some calderas (Krakatau type) form as the result of large scale effusion of pumice from a central vent. An enormous volume of the ejected pumice flows as nuées ardentes and is deposited on and beyond the skirts of the volcano. His view has been widely accepted, and it is known that the formation of many Japanese calderas was associated with the eruption of large volumes of pumice (Kuno, 1954).

Thus, pyroclastic flow deposits (nuée ardente in the broad sense) are now known to occur in volcanic districts throughout the world, and in the circum-Pacific volcanic region in particular. The importance of their origin is now being realized. The term pyroclastic flow includes the following words, the definition of which may vary with user; nuée ardente, glowing cloud, Glutwolke, Peléan cloud, hot (dry) avalanche, sand-flow, tuff-flow, ladoe (ladu), etc.

PREVIOUS CLASSIFICATIONS

Pyroclastic flows have been classified in various ways. Outlined below are the classifications of Lacroix (1930), Escher (1933) and Macgregor (1952, 1955).

Classification by Lacroix and Escher

I { Nuée ardente peléenne d'esplosion dirigée (Lacroix)
Glowing cloud of Pelée type (Escher)

This type is represented by pyroclastic flows resulting from the horizontal ejection of essential materials with a given initial velocity. This type is initiated by an explosion on the side of a fresh lava dome at the summit of a volcano, and is typified by the nuée ardente of Mt. Pelée on May 8, 1902.

II { Nuée ardente d'explosion vulcanienne (Lacroix)
Glowing cloud of St. Vincent type (Escher)

When ejecta from the summit crater is thrown vertically into the air and later cascades downslope, the resultant pyroclastic flow belongs to this type. A large number of nuées ardentes of this type were observed at Soufrière Volcano on St. Vincent Island during the 1902 activity.

III { Nuée ardente peléenne d'avalanche (Lacroix)
Glowing cloud of Merapi type (Escher)

This type comprises pyroclastic flows of small scale produced by partial collapses of a lava dome at the summit of a volcano or of the edge of a thick lava flow. Also belonging to this type are those with no initial horizontal velocity derived from minor explosions on the flank of a dome or from the summit of a volcano. Many examples of this type have been observed at Merapi Volcano, Java.

IV { Nuée ardente du Massif du Katmai (Lacroix)
Glowing cloud of Katmaian type (Fenner, 1937)

A typical example is known as the "sand-flow" from the 1912 eruption of Katmai Volcano.

Macgregor (1952, 1955) subdivided the above classification and made a detailed chart based upon; 1) whether the nuée ardente was accompanied by explosion, 2) whether it was generated in a lava dome, on the summit or the flank of a volcano, or if it was ejected out of an open summit crater, 3) whether it was caused by collapse of the side of a dome, and whether it was ejected in the horizontal direction or thrown vertically into the air, 4) whether the rock was andesitic or rhyolitic, etc.

However, none of the classifications cited above is perfect. These classifications made a reasonable arrangement of the known examples of pyroclastic flows, but too much attention was paid to precise divisions so that some examples, such as the Kambara nuée ardente, failed to be grouped in any of the above-mentioned types. A most noticeable defect in the classifications is that the marked differences between the nuée ardente in the strict sense and the Katmai type pumice flow were ignored. In fact, the inadequacy of these classifications is reflected by the confusion in the present usage of the term nuée ardente.

NEW CLASSIFICATION

Individual examples of pyroclastic flows that have been reported lately from many parts of the world (as well as from Japan) may be most appropriately classified by the following division.

1. Nuée ardente in the strict sense.

2. Pyroclastic flow of the intermediate type.

3. Pumice flow.

The viscosity of essential blocks (fragments of magma) is the basis of this classification, hence the classification is fundamentally different from any of the previous classifications. The nuée ardente in the strict sense corresponds to the type with the highest viscosity and the pumice flow represents the lowest viscosity. The viscosity of the essential blocks was inferred from the characteristics of the deposits as summarized in Table 1 (especially the porosity). Viscosity as used here refers somewhat vaguely to the viscosity of the mass in the time interval between extrusion and deposition (and solidification).

As is seen in Table 1 and from the description of each type to be mentioned later, the volume of the deposit (roughly proportionate to the volume of effused magma) increases as the viscosity decreases. This relation is generalized in Figure 1. With the viscosity as inferred from the characteristics of the deposits as the abscissa and the volume of the deposits as the ordinate, most pyroclastic flows concentrate in the cross-hatched area.

Table 1

<table>
<tr><th rowspan="2">Characteristics</th><th colspan="4">Type of Flow</th></tr>
<tr><th>Nuée ardentes in the strict sense</th><th>Pyroclastic flow of intermediate type</th><th colspan="2">Pumice flow</th></tr>
<tr><td>Porosity of block</td><td>Small</td><td>Intermediate</td><td colspan="2">Large</td></tr>
<tr><td>Shape of block</td><td>Angular to subangular</td><td>Subangular to rounded</td><td colspan="2">Rounded</td></tr>
<tr><td>Ratio of ash to block</td><td>Small (to large)</td><td>Intermediate</td><td colspan="2">Large</td></tr>
<tr><td>Distribution of blocks in deposit</td><td></td><td>Uniform</td><td colspan="2">Uniform to irregular</td></tr>
<tr><td>Bread-crust structure</td><td>Occasional</td><td>Occasional</td><td colspan="2">None</td></tr>
<tr><td>Welding in the central part of deposit</td><td>None</td><td>None to intermediate</td><td>None to slight</td><td>None to marked</td></tr>
<tr><td>Degree of flatness of block</td><td>None</td><td>None to intermediate</td><td colspan="2">None to marked</td></tr>
<tr><td rowspan="2">Mode of eruption</td><td rowspan="2">Effused from summit crater or result from collapse of lava dome or thick lava flow</td><td rowspan="2">Effused from central vent</td><td colspan="2">Effused from central vent or fissure</td></tr>
<tr><td>Does not form caldera</td><td>Forms caldera</td></tr>
<tr><td>Average thickness</td><td>Several cm to several m</td><td>2 or 3 m to several tens of m</td><td colspan="2">Several tens of m to more than 100 m</td></tr>
<tr><td>Volume</td><td>$< 0.01\ km^3$</td><td>$< 1\ km^3$</td><td>$< 10\ km^3$</td><td>$> 10\ km^3$</td></tr>
<tr><td>[Volume-viscosity relations]</td><td colspan="4">Low ⟵ Amount of ejecta ⟶ High
Small ⟵ Viscosity of ejecta ⟶ Low</td></tr>
</table>

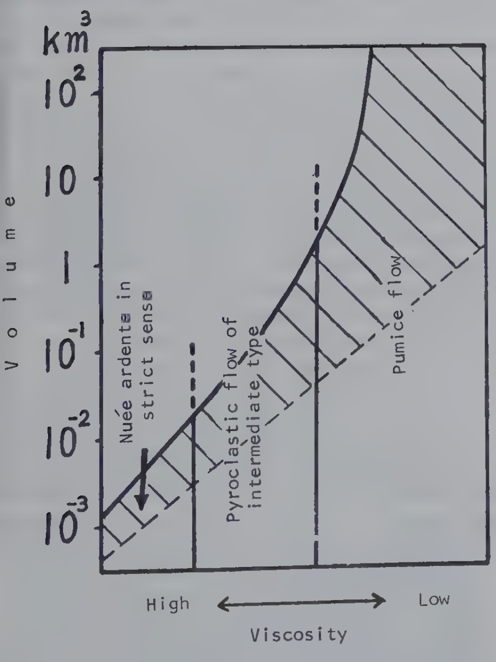

FIGURE 1.

CHARACTERISTICS OF PYROCLASTIC FLOW DEPOSITS

The mechanism of movement of nuées ardentes (already discussed) is thought to be applicable to all types of pyroclastic flows. Pyroclastic flow deposits also have common characteristics as will be outlined in the following paragraph, and the characteristics can be used as the basis of discriminating them from other pyroclastic deposits (such as mud flow deposits and deposits of fallen pumice).

Pyroclastic flow deposits cover the ground surface uniformly, irrespective of minor topographic relief, but are controlled by major relief of the initial topography as they are seen to flow into depressions. In spite of their apparent level upper surface, the thickness of the deposits is not uniform because the base conforms to the initial topography. Cross-sections reveal that the deposits are ill-sorted and abound in fine-grained material, displaying no distinct stratification. The deposits consist, for the most part, of essential materials, and have characteristics which suggest that the temperature of flows at the time they were generated was as high as that of the parental magma (such as superficial oxidation, existence of carbonized wood, welding, columnar joints,

magnetism in all blocks (Aramaki, 1956, etc.). These rocks are restricted to andesites, dacites or rhyolites; the groundmass is vitreous.

Nuée ardente in the Strict Sense

Examples: Pelée Volcano (1902, 1929-1931) (Lacroix, 1904; Perret, 1937)

Soufrière Volcano (1902) (Anderson and Flett, 1903)

Merapi Volcano (1930-1931, etc.) (Neumann van Padang, 1933, 1953)

Sakurajima Volcano (1914, 1939) (Omori, 1916; Kato, 1916; Tsuya and Minakami, 1940)

Asama Volcano, Kambara nuée ardente (1783) (Aramaki, 1956)

Pyroclastic flows of this type are generated when part of almost solidified magma exposed on the ground collapses, or when highly viscous magma is thrown out of the crater by explosion, hence the volume of magma that separates from the main body to be ejected out is always limited. The volume of the essential materials in the Kambara nuée ardente was 0.001 to 0.01 km^3 (Aramaki, 1956) and that of the nuée ardent of Merapi Volcano in the explosion of December 19, 1929 was 0.008 km^3 (Neumann van Padang). The values in other examples of nuées ardentes seldom seem to exceed the above. The resultant deposits are much thinner than those of intermediate type pyroclastic flows or of pumice flows. Rock blocks are generally, but not always, compact and angular. Fine-grained materials are less abundant than blocks, and gigantic blocks are often seen to protrude out of a thin deposit of ash. The destructive force of nuées ardentes against objects on the ground is occasionally very great. The Kambara nuée ardente displayed a strong erosive power even on a gentle slope, scooping the ground as deep as 40 m. Pyroclastic flows of this type travel a distance of only about 10 km. from the crater at the most, but the materials can be mixed with water and unconsolidated surficial materials and become hot mud flows that spread farther from the crater.

Pyroclastic Flows of the Intermediate Type

Examples:	km^3
Asama Volcano (Aramaki, 1956)	
Agatsuma nuée ardente (1783)	0.1
Oiwake nuée ardente	0.5
Kotaki nuée ardente	0.05
Hakone Volcano (Kuno, 1950)	
central cone nuée ardente	-
Myoko Volcano, central cone nuée ardente	1
Nyoko-Akanagi Volcano, (Yamasaki, 1954)	
Uehara pyroclastic flow	0.4

Pyroclastic flows of this type have characteristics intermediate between nuées ardentes in the strict sense and pumice flows. No distinct boundary can be drawn as these two types grade into one another. Pyroclastic flow deposits of this type have been recognized only in very recent times, and foreign references are still very few. This is probably because these deposits have been overlooked (or mistaken for mud-flow deposits). Such deposits are now thought to be quite common. The volume of deposits of intermediate type pyroclastic flows is much greater than that of nuées ardentes in the strict sense, and generally amounts to 0.1 to 1 km^3. Inferring from the nature of the deposits, the viscosity of magma (mean value from the time the magma was ejected until it was deposited) must be smaller than that of nuées ardentes in the strict sense. All cases cited above were ejected from summit craters of stratovolcanoes, and some of them preceded the birth of a dome of cognate rock.

The porosity of blocks in the deposits is intermediate between the other two types, but is fairly variable. Blocks are mostly rounded; few are angular, and some have bread-crust structure (as exemplified by blocks of the Agatsuma and Oiwake nuées ardentes). Fine-grained material is much more abundant that in nuées ardentes in the strict sense, and is enough to bury all blocks. Throughout the deposits, the distribution of blocks is relatively uniform (in both horizontal and vertical directions). The deposits are sometimes unconsolidated (Oiwake, Hakone and Myoko nuée ardentes) and sometimes half consolidated where columnar joints are developed and blocks are somewhat flattened (Agatsuma, Kotaki and Uehara nuées ardentes).

Pumice Flows

Deposits of this type can be defined as a product of effusion of the least viscous and the most voluminous magma of all three types. The magma, for the greater part, is homogeneous and fully vesiculated, and rarely is compact. The deposits are composed chiefly of pumice and pumiceous ash. The amount of ash is much larger than in the other two types of pyroclastic deposits. Pumice is always rounded, and is uniformly distributed throughout the deposits or is concentrated in lenses.

The volume of these deposits varies but can be roughly grouped into the following two types:

1) Pumice flows of small scale ($<$ 10 km^3 in volume)

Examples:	km^3
Komagatake Volcano (1929)	0.2
Akagi Volcano	0.2
Haruna Volcano	0.2
Nantai Volcano (Yamasaki, 1957)	0.8
Takahara Volcano	1.2
Asama Volcano (Aramaki, 1956)	2
Kusatsu-Shirane Volcano	3
Katmai Volcano (Fenner, 1937)	4

Small scale pumice flows grade into the intermediate type of pyroclastic flow. In most cases, pumice flows are ejected from the central crater of a stratovolcano, but effusion of pumice flows of this type does not result in subsidence great enough to form a caldera. Deposits are seldom consolidated and columnar joints are rare.

2) Pumice flows of large scale (> 10 km^3 in in volume)

Examples:	km^3
Hakone Volcano, second stage caldera (Kuno, 1953)........	15
Toya caldera (Ishikawa, Minato, Kuno, Matsumoto and Yagi, 1956) ..	19
Ata caldera (Matumoto, 1943)	27
Crater Lake caldera (Williams, 1942) ..	43
Towada caldera (Ishikawa, Minato, Kuno, Matsumoto and Yagi, 1956)...	45
Shikotsu caldera (Ishikawa, Minato, Kuno, Matsumoto and Yagi, 1956)...	90
Aira caldera (Matumoto, 1943)	150
Aso caldera (Matumoto, 1943)	180

Large scale pumice flows often cover an area of 1,000 km^2 or more, and make important geological units. All of the pumice flows cited above are distributed around calderas, indicating a genetic relation between the effusion of pumice and the birth of calderas. Williams (1941) called this kind of caldera the Krakatau type. From the above list it is known that Krakatau-type calderas form when the volume of ejected pumice exceeds 10 km^3. On the other hand, some larger pumice flows are accompanied by no distinct calderas, such as the deposits in New Zealand, Sumatra, eastern California, Yellowstone Park, and southern Peru. These deposits, called ignimbrites by by some people (Marshall, 1935), attain a volume of 100 to 1,000 km^3, and are thought to have been effused from more than one fissure. It must be noted, however, that the deposits of large scale pumice flows result from two or more eruptions (sometimes probably more than ten), hence the volume of individual flows is smaller than the values mentioned above.

The deposits of large scale pumice flows are often strongly welded, and form welded tuff (especially in the central portion of the cross-sections). Many such welded tuffs consist of parallel obsidian lenses in a consolidated matrix of vitric ash, and display columnar joining. The lenses of obsidian are inferred to have resulted from the following process: fragments of magma that failed to vesiculate and form pumice were deposited, then squeezed in the vertical direction due to the weight of the deposits, and thus were flattened. (However, the idea has been popular that obsidian lenses are compressed pumice blocks in which vesicles have been flattened and rehealed.)

CONCLUSION

The classification of pyroclastic flows presented here is very rough, and its objectives were merely to establish a general framework. There are exceptional examples of pyroclastic flows that cannot be classified into any of the groups. It is evident, therefore, that the writer's classification is still imperfect. Hence, further study is required on the petrologic characteristics of ejecta and for a correlation between the volume of ejecta and the nature of the initial magma (as inferred from the petrology of the ejecta). It will be possible to establish a more reliable classification with appropriate subdivisions, but it may also be very difficult, because it involves the problem of selecting the most appropriate physical and chemical features that would furnish grounds for classification or subdivision.

In the 1783 activity, the summit crater of Asama Volcano erupted showers of pumice, scoria flows (here classified as a small scale pumice flow), a pyroclastic flow of the intermediate type, a nuée ardente in the strict sense, and a lava flow, in this order. Chemical analyses revealed no marked changes in the major constituents of the magma throughout all stages of this activity. Therefore, the above-mentioned variation of the mode of eruption must be attributed to differences in volatile content (which is not known from the analytical data of solid matter), or to possible differences in physical conditions. In either case, the cause of variable modes of eruption cannot be determined by present petrologic methods. This suggests a direction in which our future study should be focused.

The writer's sincere thanks are due Prof. Hisashi Kuno, Prof. Toshio Ishikawa and Prof. Masao Yamasaki, as well as many of the participants at the 1956 spring and autumn sessions of the Society of Geophysical Volcanology of Japan, for their valuable discussions on this classification.

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AUTHOR'S POSTCRIPT TO THE PRESENT TRANSLATION

I would like to acknowledge mistakes made in my interpretation of the literature on some foreign nuées ardentes, especially those on St. Vincent as pointed out by Hay (1959). I am planning to publish a revised classification in the near future which will retain the basic three-fold division of pyroclastic flows as presented herein.

S. Aramaki,
December 1960.

Review Section

Serdyuchenko, D. P., CLASSIFICATION OF MONTMORILLONITE MINERALS: Mineral. Sbornik, Lvov. Geol. Obshch., no. 10, 1956, pp. 132-135. A summary by George V. Chilingar, University of Southern California.

The modern classification of montmorillonite minerals can and should be made on crystallochemical basis (fig. 1, also see Chilingar, 1954, 1955).

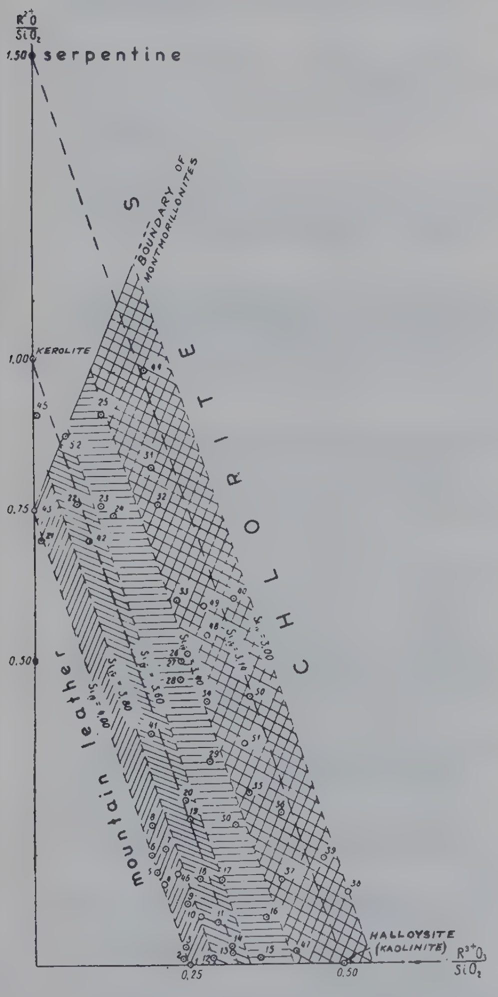

FIGURE 1. Classification diagram of montmorillonite minerals (after Serdyuchenko, 1956, p. 135)

- montmorillonites proper (Si_{IV} = 4.00 to 3.80);
- beidellite and nontronites (Si_{IV} = 3.79 to 3.60);
- saponites (Si_{IV} = 3.59 to 3.40;
- parahalloysites (low-in-silica montmorillonites), Si_{IV} = 3.39 to 3.14 (and possibly as low as 3.00)

Serdyuchenko's main subdivisions are made on the basis of composition of tetrahedral layers:

1) Montmorillonites proper (Si_{IV} = 4.0 - 3.8)
2) Beidellites (Si_{IV} = 3.79 - 3.60)
3) Saponites (Si_{IV} = 3.59 - 3.40)
4) Parahalloysites – montmorillonites poor in silica (Si_{IV}= 3.39-3.14 and as low as 3.00)

Depending on the isovalent replacements (Al_2 – $Fe_2{}^{3+}$ -- Cr_2), in each one of these groups one can distinguish aluminum montmorillonites (montmorillonites), ferrimontmorillonites, chromium montmorillonites, beidellites, nontronites (ferribeidellites), chromium beidellites, etc.

Depending on the heterovalent isomorphic replacements ($R_3{}^{2+}$ – $R_2{}^{3+}$), there are iron($Fe_3{}^{2+}$), nickel (Ni_3), magnesium (Mg_3), copper ($Cu_3{}^{2+}$), and zinc ($Zn_3{}^{2+}$) varieties; or varieties of mixed composition ($R_3{}^{2+}$ + $R_2{}^{3+}$). If octahedral layers contain more than 50 percent of any particular atom such as Mg, Cu, and Zn, then these are magnesium, copper, and zinc varieties, respectively. In case of presence of such rare elements as Cu, Zn, and Li, however, montmorillonites should retain a prefix "copper-bearing", "zinc-bearing", "lithum-bearing, "etc.

The trivalent iron in octahedral layers imparts yellowish reddish-brown colorations to montmorillonite minerals, whereas the presence of Fe^{3+} in tetrahedral layers give rise to yellowish green colors. Simultaneous presence of divalent and trivalent iron, however, lowers the coloration, even to black (some hisingerites and chlorophaites). The montmorillonite minerals with considerable Cr^{3+} content in octahedral and partly tetrahedral layers, are usually called volchonskoites.

As shown in Figure 1, where $R^{2+}O/SiO_2$ ratio is plotted versus the $R_2{}^{3+}O_3/SiO_2$ ratio, the area occupied by montmorillonites is bounded by chlorites to the right and "palygorskites" (mountain leather) on the left. It should be remembered, however, that the area to the right of serpentine-kaolinite line could contain points representing rare, very low-inosilica monmorillonites and very rare, very rich-in silica chlorites (close to serpentine). It is interesting to note, that some chlorites of sedimentary origin have high swelling characteristics.

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-- Managing Editor

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RUSSIAN PAPERS PREPARED FOR 21st INTERNATIONAL GEOLOGICAL CONGRESS, 1960

According to a pamphlet, in Russian, distributed at the meetings of the Twenty-first International Geological Congress, Soviet geologists had assembled a far greater number of papers than were listed in the official program and abstracts volume, or were published in English translation in the proceedings volumes:

We give here the complete translation of this pamphlet, which is essentially a list, by author and title, of all the papers the Soviets "dedicated" to the Congress. Of the 23 volumes which are indicated to contain the papers, the Library of Congress is known (as of February 15, 1961) to have accessioned 12. According to their accession notices (IGR) Reference Sections, v. 3, no. 2, p. 175; also no. 4, p. 350, under "monographic works") the volumes contain the complete Russian text and English summaries.

The known availability of this material in the United States is indicated, in brackets within the lists, as follows: "Prog." - The paper cited is included by title and English abstract in the Programme, and Volume of Abstracts, of the Reports of the Twenty-first Session, Norden, International Geological Congress, Copenhagen, 1960. "Trans." - The paper cited appears in full English translation in Reports of the Twenty-first Session, Norden, International Geological Congress, Copenhagen, 1960. Part and page number in the Reports is indicated. "Avail. at LC" - The volume cited has been accessioned by the Library of Congress according to their Monthly Index of Russian Accessions, through January, 1961. --M. R.

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6. A. I. Tugarinov, E. E. Vainshtein. Rare earths in rocks.
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8. L. F. Borisenko, V. V. Shcherbina. Geochemistry of scandium.
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7. A. A. Brodsky. Some theoretical provisions of the hydrochemical method of prospecting for sulfide deposits.
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13. A. D. Shcheglov. Genetic peculiarities of mercury-antimony-tungsten deposits of the Transbaikal.
14. N. V. Petrovskaya. Character of gold-bearing mineral associations and genetic types of gold ores in the U. S. S. R.
15. M. N. Albov. Secondary zoning of gold-bearing deposits with examples from the Urals.
16. Ya. N. Belevtsev, R. I. Siroshtan. Genetic types of Precambrian iron ore deposits.

Problem 17. Mineralogy and Genesis of Pegmatites (Editor-in-Chief, G. P. Barsanov). Academy of Sciences of the U. S. S. R.; 5 rubles. [Avail. at LC]

1. A. I. Ginzburg. Geochemical peculiarities of the pegmatitic process. [Prog., Trans., pt. 17, p. 111]
2. K. I. Babayev. Genetic peculiarities of granitic pegmatites of Central Asia.
3. Yu. P. Ivensen. Peculiarities of geology and material composition of granitic pegmatites.
4. V. D. Nikitin. Conditions of formation for rare-metal bearing and pegmatitic rock.
5. N. P. Yermakov. Granitic pegmatites, silexites and quartzoliths of Kazakhstan.
6. E. I. Semenov. Geochemistry and mineralogy of supergene and epithermal processes in alkaline massifs and affiliated pegmatites.
7. K. A. Vlasov. Alkaline pegmatites and their genesis.

Problem 18. Structure of the Earth Crust and Deformation Rocks (Editor-in-Chief, A. V. Peyve). Academy of Sciences of the U. S. S. R.; 13. 50 rubles. [Avail. at LC]

1. A. T. Aslanyan. Dynamic problems of geotectonics.
2. M. V. Gzovsky. Tectonophysics and problems of structural geology.
3. V. A. Magnitsky. Interrelation between the earth's crust and the substance of earth's mantle according to geophysical data.
4. S. I. Subbotin. Causes and mechanism of formation of platform depressions and geosynclinal subsidences in the earth's crust.
5. G. D. Azhgirey. Geologic conditions of formation, kinematics and dynamics of geosynclinal folds.
6. A. V. Peyve. Faults and their role in the structure and evolution of the earth's crust.
7. Yu. M. Pushcharovsky. Peculiarities of tectonic structure and evolution of marginal depressions.
8. P. N. Kropotkin. Neotectonics and geophysical data on thickness and deformations of the earth's crust.
9. V. E. Khain. Basic types of tectonic structures, the peculiarities and causes of their development. [Prog., Trans., pt. 18, p. 215]
10. Yu. M. Sheinman. Great renovations in the tectonic history of the earth.
11. M. S. Nagibina. History of evolution of structures of the Mongolian Okhotsk belt.
12. M. V. Muratov. Tectonic structures of the Alpine geosynclinal region of eastern Europe and Asia Minor and the history of their evolution. [Prog., Trans., pt. 18, p. 137]
13. V. I. Slavin, D. Yaranov. Intermontane massifs of the European part of the Alpine geosynclinal region.
14. D. S. Kizevalter, V. N. Robinson, V. I. Slavin. Development of the Great Caucasus structure during the Paleozoic.
15. I. V. Kirillova, A. A. Sorsky. Tectonics and seismicity of the Caucasus.
16. E. Sh. Shikhalibeyli. Problem of deep structure of the south Caspian depression and vicinity.
17. M. G. Agabekov. Mantle folds of the Apsheron petroliferous region.
18. P. O. Gamkrelidze. Mesozoic-Cenozoic orogenic phases of the Alpine zone in the southern U. S. S. R.
19. V. V. Glushko, I. F. Klitochenko, V. S. Popov, M. V. Chirvinskaya. Tectonics of the Ukraine.
20. A. A. Pronin. Deep tectonics and formation of granites of the Urals.
21. I. P. Atlasov, V. N. Sokolov. Geologic structure of the central Soviet Arctic.
22. O. L. Eynor. Problem of evolution of the Russian platform.

Problem 19. Caledonian Orogeny (Editor-in-Chief, E. V. Pavlovsky). Academy of Sciences of the U. S. S. R.; 5 rubles. [Avail. at LC]

1. A. A. Bogdanov. Basic regularities of the evolution of Paleozoic folding of the U.S.S.R. [Prog., Trans., pt. 19, p. 126]
2. Yu. M. Sheinman. Some features of Caledonides of Eurasia.
3. V. P. Nekhoroshev. Manifestations of Caledonian orogeny in the Altai.
4. V. A. Unksov. Peculiarities of the evolution of Caledonides in south-central Siberia.
5. K. V. Radugin. Cambrian folding.
6. N. S. Zaitsev. Comparative tectonics of eastern Sayany and the Scottish Highlands.
7. L. A. Zonenshain, G. A. Kudryavtsev. Position of major granitoid intrusions in the tectonic structure of the Sayany-Tuva mountain region.
8. V. I. Knauf. Regularities of the manifestation

evolution of organisms.

15. A. V. Sidorenko. The preglacial (pre-Quaternary) continental stage of evolution of the Kola peninsula and eastern part of the Baltic shield.
16. A. B. Ronov, V. E. Khain. Mesozoic paleogeography and geology of continents. [Trans., pt. 12, p. 152]

Problem 13. Petrographic Provinces, Volcanic and Metamorphic Rocks (Editor-in-Chief, G. D. Afanasyev). Academy of Sciences of the U. S. S. R.; 17.50 rubles. [Avail. at LC]

I. General Problems

1. G. D. Afanasyev. Regularities in the development of magmatic processes in folded regions of the U. S. S. R.
2. Yu. A. Kuznetsov. Magmatic formations and their classification. [Prog., Trans., pt. 13, p. 94]
3. A. P. Lebedev. Peculiarities of magmatic processes and mineralization on platforms and ancient shields.
4. M. A. Favorskaya. Role of magmatism in the mineralization of rare and base metals.
5. G. M. Gapeyeva. Lamprophyres.
6. Yu. I. Polovinkina, T. N. Ivanova. Study of magmatic formations — the first problem of petrography.
7. V. S. Koptev-Dvornikov and others. Granitization in relatively shallow horizons.
8. F. K. Shipulin. Granitoid dikes and some peculiarities of the genesis of ore solutions.
9. O. A. Vorobyeva. Alkaline rocks of the U. S. S. R. [Prog., Trans., pt. 13, p. 7]
10. I. D. Tsarovsky. Phenitization and mariupolization as types of alkaline metasomatic rock alteration.

II. The Caucasus and Carpathians

11. R. N. Abdullaev. Magmatic processes in Azerbaidzhan.
12. G. S. Dzotsenidze. Petrographic provinces of Transcaucasia.
13. G. M. Zaridze. Volcanic and metamorphic rocks of [Russian] Georgia.
14. E. F. Maleyev. Main stages of the evolution of Neogene volcanism in the Soviet Carpathians and associated metallogeny.

III. The Russian Platform

15. M. A. Volotovskaya. The Karelian-Kola peninsula petrographic province of ultrabasic, alkalic and carbonate rocks.
16. N. A. Yeliseyev. Ultrabasic and basic intrusions of the Kola peninsula.
17. V. A. Yershov. Ultrabasic rocks of the Ukraine and associated mineral deposits.
18. K. A. Shurkin. Archean magmatism of north Karelia.
19. Z. G. Ushakova. Lower Paleozoic trap rocks of the Russian platform.
20. I. A. Petersilye. Combustible gases and bitumens in alkaline rocks of the Kola peninsula.

IV. The Urals — Taimyr

21. A. A. Pronin. The Uralian petrographic province of magmatic and metamorphic rocks.
22. Yu. E. Moldavantsev, A. S. Perfilyev, N. P. Kheraskov. Regularities in distribution of magmatism and metamorphism of the northern Urals in relation to tectonic structures.
23. S. V. Moskaleva. Role of metasomatism in formation of some rocks of gabbroid and hyperbasic composition in the Urals.
24. D. S. Shteinberg. New data on serpentinization of dunites and peridotites of the Urals.
25. M. G. Ravich. Magmatic and metamorphic rocks of the mountainous part of Taimyr.

V. Siberian Platform and Its Folded Framework

26. Yu. N. Khiltov. Some problems of the mechanism of formation of kimberlite bodies in Yakutia.
27. G. V. Pinus. Magmatism of the Caledonides in the Altai-Sayany folded region.
28. I. S. Rozhkov, I. Ya. Nekrasov. Peculiarities of magmatism in the northeastern part of Yakutia.
29. I. V. Belov. Mesozoic-Cenozoic rocks of the Baikal region.
30. S. I. Naboko. Quaternary and Recent volcanism of Kamchatka and the petrochemical peculiarities of lavas.
31. G. S. Gorshkov. Quaternary volcanism and petrochemistry of Recent lavas from the Kurile Islands.

Problem 14. Problem of Granite-Gneisses (Editor-in-Chief, N. P. Semenenko). Academy of Sciences of the U. S. S. R.; 11.45 rubles. [Avail. at LC]

1. D. S. Korzhinsky. Regime of acidity-alkalinity during magmatic processes. [Prog., Trans., pt. 21, p. 160]
2. N. P. Semenenko. Theory of metamorphism of mobile zones. [Prog., Trans., pt. 14, p. 62]
3. V. S. Sobolev. Role of high pressures during metamorphism. [Prog., Trans., pt. 14, p. 62]
4. N. G. Sudovikov. Granites and ore formation.
5. V. V. Tikhomirov. Problem of evolution of the earth's crust and importance of metasomatism during this process.
6. N. I. Polovko. Principles of classification and stages of metamorphism in ferruginous-cherty rocks of the Ukraine.
7. R. I. Siroshtan. Metamorphism of aluminum silicate rocks in ferruginous-cherty rocks of the Ukraine.
8. G. M. Zaridze, N. F. Tatrishvili. Stages of metasomatism.
9. I. D. Sobolev. Petrology, age and conditions of formation of gneisses in the Urals.
10. A. A. Marakushev. Parageneses of alumina-supersaturated Archean crystalline schists of the Aldan shield.
11. I. N. Govorov. Greisenization of carbonate rocks.
12. G. L. Pospelov. Phenomena of magmatic replacement in subeffusive facies, and subeffusive stages of evolution of compound magmatic complexes in western Siberia.
13. I. F. Trusova. Granitization and metamorphism of Precambrian rocks of Central Kazakhstan.
14. G. N. Vertushkov. Granitization of ferruginous quartzites in the Ufaley region of the central Urals.
15. Ya. N. Belevtsev, A. I. Strygin. Granitization of ferruginous rocks and the process of ore formation.
16. V. A. Zharikov. Magmatic replacement of carbonate series.

of Caledonian orogeny in Tien Shan.
9. G. A. Krasheninnikov. Sedimentary upper Paleozoic rocks in the Caledonides of south Siberia and northwestern Europe. [Prog., Trans., pt. 19, p. 137]
10. I. V. Luchitsky. Middle Paleozoic history of ancient Caledonides of Siberia.
11. I. I. Belostotsky. Devonian structure and history of the Altai.

Problem 20. Applied Geology. "Problems of Metallogeny" Division (Editor-in-Chief, A. A. Amiraslanov). Gosgeoltekhizdat; 8. 75 rubles.
1. I. G. Magakyan. Metallogenetic map of the World and some regularities in distribution of ore deposits in the earth's crust.
2. G. A. Tvalchrelidze. Regularities in manifestation of mineralization in the formation of folded zones (as exemplified by the Black Sea Alpine geosynclinal region).
3. E. A. Radkevich. Problem of types of ore-bearing territories.
4. M. B. Borodayevskaya, N. I. Borodayevsky. Petrogenesis, structural types and the metallogeny of minor intrusions.
5. I. S. Rozhkov. Regularities in distribution of mineral deposits in Yakutia.
6. V. T. Matveyenko. Structures controlling magma and mineralization of the southeastern U. S. S. R.
7. D. P. Serdyuchenko. Genetic types of sedimentary-metamorphic iron ores in the Precambrian.
8. Yu. P. Kazansky. Upper Cretaceous oölitic iron ores of the central Ob Valley region.
9. A. A. Amiraslanov. Geologic characteristics, methods of prospecting, exploration and evaluation of bedded copper and lead-zinc deposits. [Prog.]
10. G. A. Ostrovskaya. Peculiarities of formation of lead-zinc ores in carbonate tuffs.
11. S. S. Mkrtchyan. Copper-molybdenite formation in Armenia.
12. V. S. Domarev. Primary zoning of mineralization in cupriferous sandstones.

Problems of Sedimentology. Papers prepared on the occasion of the Meeting of the International Association for Sedimentology (Editor-in-Chief, L. V. Pustovalov). Gosgeoltekhizdat; 11. 20 rubles.
1. V. V. Veber, N. M. Turkeltaub. Formation of gaseous hydrocarbons in Recent marine sediments.
2. S. G. Sarkisyan, N. A. Mikhaylova. Devonian petrography and paleogeography of the terrigenous rocks of Bashkiria and Tataria in the Volga-Urals petroliferous region.
3. G. I. Teodorovich, B. Ya. Polonskaya. Mineralogical and geochemical features of Devonian petroleum source beds of the Volga-Urals.
4. T. N. Davydova, Ts. L. Goldshtein, L. S. Kaminskaya. Genetic approach to paleogeography as exemplified by the Bureya coal basin.
5. E. I. Sokolova. Physicochemical characteristics of some sedimentary iron and manganese ores and enclosing rocks.
6. G. Yu. Romanova. Experience with lithologic and petrographic correlation of Riphean rocks of the Urals, Yenisey range and Malyy Khingan.
7. L. V. Pustovalov, N. I. Yudin. Iron-ore deposits of the Angaro-Pitsky region of eastern Siberia. [Prog.]
8. M. E. Berdichevskaya, A. M. Leites. Some peculiarities of structure of bedded copper deposits as shown by cupriferous sandstones of eastern Siberia.
9. A. V. Kopeliovich. Genesis of lead-zinc deposits in ancient rocks in the southwest Russian platform.
10. P. S. Saakyan, V. M. Saakyan. Ore-bearing sedimentary tuff of the Lori basin.
11. B. M. Gimmelfarb, A. M. Tushina. Phosphorite-bearing deposits of the Karatau basin.
12. D. P. Serdyuchenko. Boron-bearing sedimentary-metamorphic rocks.
13. P. P. Smolin. Basic features of the epigenetic and metamorphic evolution of dolomites.
14. M. S. Shvetsov. Problem of diagenesis. [Prog.]
15. G. F. Krasheninnikov. Paleogeographic methods based on facies analysis.
16. L. N. Botvinkina. Lamination as a genetic feature of sedimentary rocks.

Theses of papers which were not part of the Symposium.
1. N. B. Vassoyevich, V. T. Vychev, D. K. Patrunov. Results and methods of study of Recent gravels along the northern coast of Sakhalin.
2. M. V. Klenova. Peculiarities of sedimentation in the Arctic basin. [Prog.]
3. L. B. Rukhin. Problem of formation of ancient alluvial deposits.
4. E. V. Rukhina. Granulometric composition of moraine deposits.
5. A. B. Ronov, A. A. Migdisov. Interrelation of normal concentrations (clarke) and high grade concentrations of alumina in argillaceous rocks.
6. N. Kh. Belous. Genetic types and facial peculiarities of iron accumulation in central Siberia.
7. G. A. Kaleda. Evolution of cherty sedimentation.
8. A. D. Sultanov. Regularities in distribution of sedimentary rocks in the Cretaceous of the southeastern Caucasus and in the productive series of Azerbaidzhan.
9. T. N. Belskaya. Lithological and paleoecological study of the Upper Devonian of the Kuznets coal basin.
10. N. G. Brodskaya. Sedimentation and Regularities in distribution of mineral deposits in the Tertiary geosynclinal basin on Sakhalin.
11. A. S. Makhnach, V. P. Kurochka. Some lithological features of pre-Ordovician deposits in the western part of the Russian platform.

Papers prepared on the occasion of the International Commission for Study of Clays (Editor-in-Chief, F. V. Chukhrov). Academy of Sciences of the U. S. S. R.; 7. 00 rubles.
1. B. B. Zvyagin. Structure of clay minerals in the light of electron-microscopic studies.
2. V. A. Drits, A. L. Kashaev. Structural features of kaolinite minerals.
3. V. A. Frank-Kamenetsky. Mixed layer intergrowths and the isomorphism of clay minerals.
4. F. V. Chukhrov, S. I. Berkin, V. A. Moleva.

Cupriferous clay minerals.
5. N. N. Smolyaninova, V. A. Moleva, N. I. Organova. A new member of the montmorillonite series containing no aluminum — sokonite.
6. N. I. Gorbunov, M. G. Semenova, Sun Da-Chen. Formation of secondary minerals during the first stage of soil formation.
7. I. I. Ginzburg, R. S. Yashina. Displacement of bases of some clay minerals by salts, their electrodialysis and hydrolysis.
8. E. G. Kulakovsky. Replacement of kaolinite by hydrargillite in the Novoselitskoye kaolin deposit of the Ukraine.
9. M. A. Rateyev. Role of climate and tectonics in the genesis of clay minerals in sedimentary rocks.
10. N. I. Titkov, V. P. Petrov, A. Ya. Neretina. Minerals and structures forming in moistened clays due to action of direct electric current.
11. V. A. Priklonsky, N. A. Oknina. Diffusion processes in argillaceous rocks.
12. F. D. Ovcharenko. Dependence between hydrophilic, sorbtion and structural-mechanical clay properties.
13. Ts. M. Raitburd. Study of clay microstructure by means of the X-ray diffraction method.
14. I. M. Gorkova. Thixotropic features of argillaceous rocks of different structural types.
15. B. M. Gumensky. Role of water transformation in the physical state of clayey soils during vibration (as demonstrated by vibrational drilling).

Problems of Ground-Water Geology. Papers prepared on the occasion of the meeting of the International Association of Ground-Water Geologists (Editor-in-Chief, O. K. Lange). Gosgeoltekhizdat; 21.80 rubles.

I. Problems of Distribution, Formation and Method of Mapping Ground Waters.
1. O. K. Lange. Distribution of ground water in the earth's crust.
2. I. K. Zaitsev, N. I. Tolstikhin. Basic features of ground-water geology of the U.S.S.R.
3. I. K. Zaitsev. Regional regularities in the hydrochemistry of ground water of the U. S. S. R.
4. G. V. Bogomolov. Basic regularities in distribution of ground water in the Russian platform.
5. M. S. Gurevich. General hydrochemical regularities of artesian basins.
6. V. I. Dukhanina. Regularities of distribution and formation of ground water of the Russian plain.
7. S. A. Shagoyants. Types of horizontal and vertical artesian zoning in basins of different structure and factors which determine them (highlights of paper).
8. I. V. Garmonov, V. M. Sugrobov, A. I. Ivanov. Regions of recharge and discharge of ground water in the southeastern part of the west Siberian lowland.
9. B. F. Mavritsky. Paleo-ground-water analysis of the west Siberian artesian basin.
10. A. I. Efimov. Ground water of the permafrost region in the eastern part of the Siberian platform.
11. V. M. Ponomarev. Basic features of ground water of permafrost areas in the U. S. S. R.
12. A. M. Ovchinnikov. Basic principles of outlining ground-water regions.
13. M. E. Altovsky, N. A. Marinov, E. G. Chapovsky, M. V. Churinov. Method of preparing ground-water maps.
14. N. I. Druzhinin. Application of EGDA method in preparing ground-water maps.
15. S. P. Prokhorov, G. N. Kashkovsky, F. I. Losev. Principles of evaluation of ground water and engineering-geologic conditions in coal areas of the U. S. S. R.
16. G. A. Mavlyanov, N. A. Kenesarin. Basic problems of ground-water geology of regions with agricultural irrigation in Central Asia and south Kazakhstan.
17. P. A. Kryukov. Problems of investigating solutions saturating sedimentary rocks.
18. A. E. Babinets. Role of interstitial solutions in the formation of vadose ground water.
19. F. A. Makarenko. Zoning of ground water and its importance in geological processes (highlights of paper).

II. Dynamics, Regime and Ground-Water Resources.
20. B. I. Kudelin, Z. A. Korobeynikova, N. A. Lebedeva. Types of maps showing ground-water resources in the zone of intensive water exchange.
21. A. A. Konoplyantseva, V. S. Kovalevsky. Problem of regional regularities of the ground-water regime.
22. F. M. Bochever. Evaluation of productive reserves of ground water in river valleys of arid regions.
23. V. D. Babushkin, I. S. Glazunov, N. G. Shevchenko. A method of exploitation of major soft-water lenses by double wells and evaluation of producing reserves of aquifers from the recharge area.
24. V. S. Lukyanov, M. A. Veviorovskaya. Application of hydraulic analogies in the investigation of ground-water filtration.
25. V. I. Aravin. Investigation of ground-water flow with a free surface and vertical axis of symmetry by means of a slit [silt?] pan.
26. K. F. Bogoroditsky. Application of gasochemical calculations for determination of the degree of water saturation of gaseous coal deposits.

III. Mineral and Thermal Waters and Their Geochemical Value.
27. V. V. Ivanov, A. M. Ouchinnikov, L. A. Yarotsky. Basic regularities in formation and distribution of mineral waters in the U. S. S. R.
28. F. A. Makarenko. Thermal waters of the U. S. S. R. as a source of energy.
29. V. V. Ivanov. Conditions of formation and composition of thermal waters in regions of Recent volcanism.
30. V. A. Pokrovsky. Temperature characteristics of ground waters of the Russian platform and adjacent geologic structures.
31. V. G. Tkachuk. Mineral waters of the southern part of eastern Siberia, their formation and prospects for utilization.
32. L. A. Yarotsky. Conditions of formation of hydrogen sulfide-bearing waters of the U. S. S. R. (highlights of paper).

3. N. V. Tageyeva. Geochemistry of oil-reservoir waters.
4. V. A. Krotova. Role of water in the formation and deterioration of oil reservoirs (highlights of paper).
5. A. A. Kartsev. Principles ground-water paleogeologic studies (during study of the genesis of oil and gas pools and in evaluation of prospects for oil and gas).
6. S. I. Smirnov. Geochemistry of ground water in the zone of supergene alteration of sulfide deposits.
7. V. V. Krasintseva. Accumulation of boron in mineral waters as the result of leaching from sedimentary rocks.
8. M. E. Altovsky. Organic matter and microflora of ground water of some regions of the U. S. S. R.
9. E. L. Bykova. Problem of studying organic matter in ground water.
0. V. V. Shtilmark. Exogenous thermal anomaly of Yangan-Tau mountain in the western Urals.

Problems of Ground-Water Geology and Engi-ering Geology in Connection with Civil Engineering

1. I. V. Popov. Some immediate problems of engineering geology in connection with ground water studies.
42. I. V. Popov. Influence of civil engineering on geology.
43. V. A. Priklonsky, N. A. Oknina. Diffusion processes in argillaceous rocks and their role in ground-water geology and engineering geology.
44. N. V. Rodionov. Principles of outlining ground water and engineering aspects in karst regions of European U. S. S. R.
45. F. V. Kotlov. Geological processes and phenomena related to the activity of man; their importance in ground-water and engineering geology.
46. I. V. Popov, E. M. Sergeyev, G. S. Zolotarev, S. S. Polyakov, G. A. Golodkovskaya. Principles of engineering geology in study of the valleys of major rivers in connection with construction of hydroelectric plants in the U. S. S. R. (as demonstrated by the Volga, Ob, Amur and other rivers).

Stratigraphic Classification and Terminology (Temporary Regulation). Interdepartmental Committee on Stratigraphy of the U. S. S. R.; 1. 25 rubles.

RECENT TRANSLATIONS IN GEOLOGY

A review of the Translation Services

This part of the Reference Section is devoted each month to a listing of the new translations of geologic significance which have become available from sources other than IGR and the established cover-to-cover journals in geology. This is done to accomplish several purposes: 1) inform geologists of the foreign literature in their field available in translation; 2) provide information necessary to avoid duplication of translation effort, and 3) advise geologists of the activities of the various organizations providing translations or related services in their field.

FRENCH TRANSLATIONS

International Geology Review has a near counterpart in the French La Chronique de Mines d'Outre-Mer et de la Recherche Minière [Journal of Foreign Mines and Mining Research]. This monthly, published by the Bureau de Recherches geologiques et minères, carries its lead articles in both French and English. French-reading geologists, however, will probably find even greater interest in the Analyses and Information "Divers" sections, since the abstracts in them are of world scope. Capsule summaries in English are included. Bibliographic references for these abstracts are classified according to geologic category, geographical area or metal resource.

This journal also publishes a monthly supplement, Liste mensuelle de Traductions, listing recent translations in geology purchasable at 0.70 NF per page through the Service d'information Geologique (S. I. G.) of the B. R. G. M., 74 rue de la Federation, Paris 15^{e}, France. Annual subscription rate for the monthly bulletin and its quarterly version, Bulletin trimestriel du Service d'Information geologique in 8 NF. Each issue of the Bulletin trimestriel also includes a major French geologic article.

Translations are listed as "in process", "currently available" or "available at reduced prices", the latter being articles reproduced in volume. Most translations are photocopies, but larger works are available only in microfilm.

The fields covered are not restricted to ore minerals, but include considerable paleontology, stratigraphy and sedimentary and applied geology with the accent on oil. Sources are almost exclusively Russian, and include some already translated into English under the AGI program, notably Izvestiya and Doklady of Akademiya Nauk, S. S. S. R.

The French are translating Razvedka i Okhrana Nedr [Exploration and Conservation of the Earth's Interior] cover-to-cover, running about eight months behind Russian publication dates. The January 1961 Bulletin trimestriel gives the following subscription information:

Issues available: Nos. 1 through 12, 1959, and Nos. 1 through 5, 1960; (No. 5 in press: No. 6 in preparation). Price: 40 NF per year overseas or 4.50 NF per issue. Orders should be addressed to: La Societe des Editions TECHNIP, 2 rue de Lubeck, Paris 16^{e}, France.

Also published cover-to-cover in French in Voprosy Mikropaleontologii [Problems in Micropaleontology]. Issues Nos. 1 and 2 are available; No. 3 was at press in January 1961. Subscription source is the same as for the Bulletin trimestriel and Liste mensuelle de Traductions.

GEOLOGIC-TRANSLATION JOURNALS

The following translation journals regularly contain translations of interest to geologists. The subsequent list of recent translations does not include articles from these journals:

Atomic Energy, published by Consultants Bureau.

Bulletin (Izvestiya) of the Academy of Sciences U. S. S. R., Geophysics, published by the American Geophysical Union.

Doklady of the Academy of Sciences of the U. S. S. R., Earth Sciences Sections, (Geochemistry, geology, geophysics, hydrogeology, mineralogy, paleontology, petrography, lithology and permafrost), published by the American Geological Institute.

Geochemistry, published by the Geochemical Society.

Geodesy and Cartography, published by the American Geophysical Union.

Izvestiya of the Academy of Sciences of the U. S. S. R., Geologic Series, published by the American Geological Institute.

Petroleum Geology, published by the Review of Russian Geology.

Problems of the North, published by the National Research Council of Canada.

Soil Science, published by the American Institute of Biological Sciences.

Soviet Geography, selected translations and reviews published by the American Geographic Society.

Soviet Physics: Crystallography, published by the American Institute of Physics.

SOURCES OF TRANSLATIONS

The current list of recent translations is from ne following: Technical Translations, vol. 5, os. 6 and 7.

An index of sources and addresses will be ound at the end of the list of translations.

Geologists and translators are invited to ubmit titles which have not been cited by serices from which we compile these lists. The ubmittal of a copy of the translation itself will e construed as an offer for IGR to publish, make opies available at cost of reproduction and/or onsign it to a major translations repository at ur discretion. Suggestions for improving this ervice are welcome.

RECENT TRANSLATIONS

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NEW RUSSIAN-ENGLISH GEOLOGIC DICTIONARY

The AGI Translations Office and a few individual geologists have received from visitors, or by mail from the Soviet Union, copies of a new and potentially useful dictionary - Russian-English Geological Dictionary, compiled by T. A. Sofiano, edited by A. P. Lebedev and V. E. Khain, published by Central Editorial Board, Foreign-language Scientific and Technical Dictionaries, Fizmatgiz. 560 pages, Moscow, 1960.

According to its Russian foreword, it consists "of about 35,000 terms, related to various branches of geological science: general geology, hydrogeology, geomorphology, petroleum geology, mineralogy, paleontology, petrography, ore deposits, stratigraphy and tectonics. General terms on geochemistry, vulcanology and engineering geology are included."

Members of AGI's Translations Committee are currently evaluating it. We hope to report their findings soon in IGR.